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August 1997

US Army Corps of Engineers
Waterways Experiment Station

Study for Flushing of Salt Lagoon and Small-Boat Harbor Improvements at St. Paul Harbor, St. Paul Island, Alaska

Coastal Model Investigation

by Robert R. Bottin, Jr., Hugh F. Acuff

WES

Prepared for U.S. Army Engineer District, Alaska

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Waterways Experiment Station
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Final report

Prepared for U.S. Army Engineer District, Alaska
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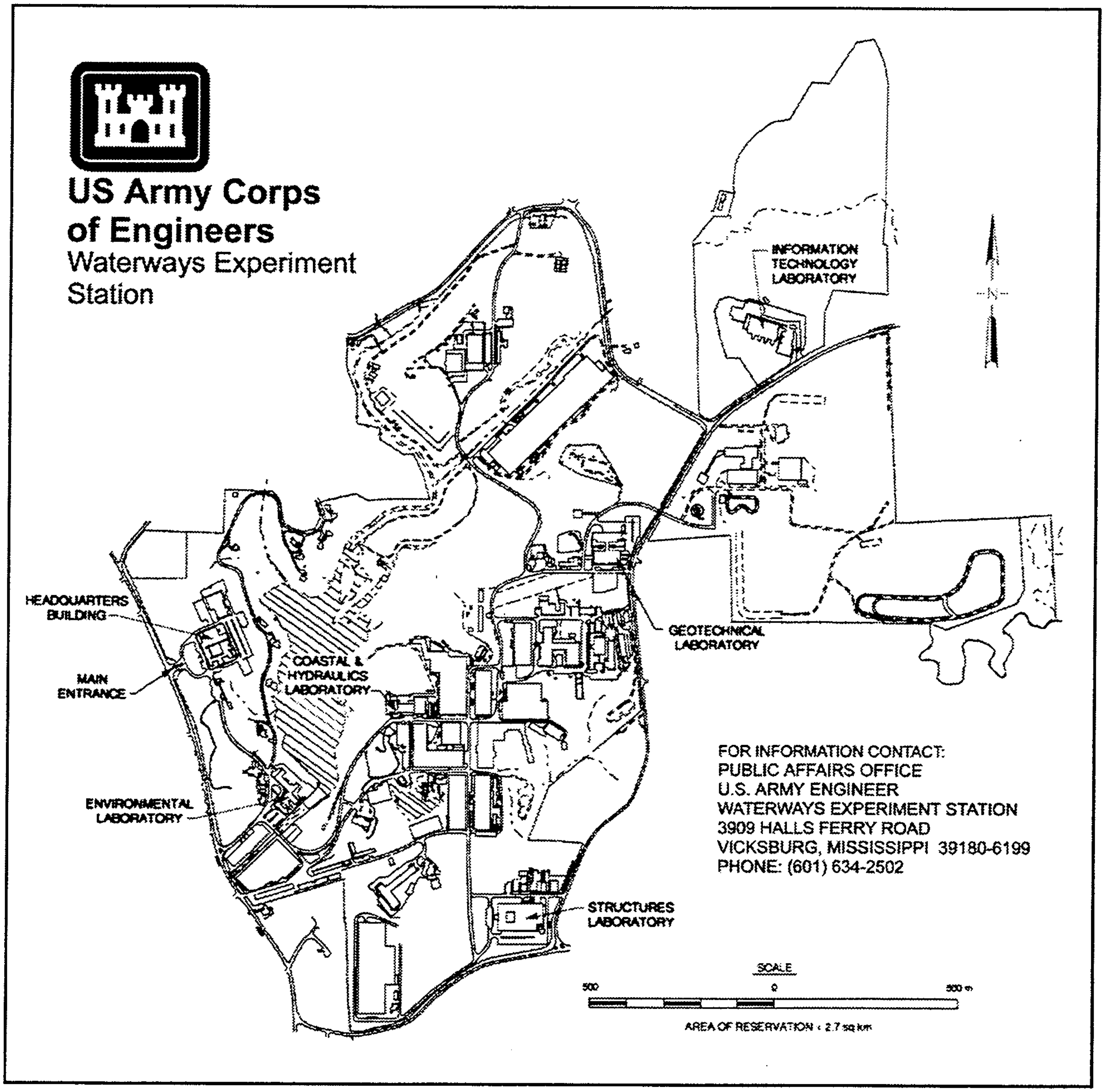

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Contents

Preface

A request for a model investigation to study harbor modifications at St. Paul Harbor, St. Paul Island, Alaska, was initiated by the U.S. Army Engineer District, Alaska, (NPA) in a letter to the U.S. Army Engineer Division, North Pacific. Authorization for the U.S. Army Engineer Waterways Experiment Station (WES), Coastal and Hydraulics Laboratory (CHL), to perform the study was subsequently granted by Headquarters, U.S. Army Corps of Engineers (HQUSACE). Funds were provided by the NPA on 30 January and 10 February 1997.

Model experiments were conducted at WES during the period February through March 1997 by personnel of the Wave Processes Branch (WPB) of the Wave Dynamics Division (WDD), CHL, under the direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director of CHL, respectively; and under the direct guidance of Messrs. C. E. Chatham, Jr., Chief of WDD; and Dennis G. Markle, Chief of WPB. Model experiments were conducted by Messrs. Hugh F. Acuff and Larry R. Tolliver, Civil Engineering Technicians, and William G. Henderson, Computer Assistant, under the supervision of Mr. Robert R. Bottin, Jr., Research Physical Scientist. This report was prepared by Messrs. Bottin and Acuff.

During the course of the study, liaison was maintained by means of conferences, telephone communications, and monthly progress reports. Mr. Ken Eisses was technical point of contact for NPA. The following personnel visited WES to attend conferences and/or observe model operation during the course of the study.

Mr. John Lockhart	HQUSACE
Mr. Ken Eisses	NPA
Mr. Alan Jeffries	NPA
Mr. John Burns	NPA
Mr. John Oliver	Consultant, NPA
Mr. Gary Wheeler	U.S. Fish and Wildlife Service
Mr. Brad Smith	National Marine Fisheries
Mr. George Watts	Consultant, City of St. Paul
Mr. John R. Merculief	City of St. Paul
Mr. Carl W. Merculief	City of St. Paul

Mr. Jacob N. Merculief	City of St. Paul
Mr. Mateo Paz-Soldan	City of St. Paul
Mr. Ernest M. Stepetin	City of St. Paul
Ms. Charlotte Kirkwood	City of St. Paul
Mr. Patrick N. Baker	Tribal Government of St. Paul
Mr. Elary Gromuff, Jr.	Tanadgusix (TDX) Corp.
Mr. Bill Arterburn	TDX Corp.
Mr. Ron Philemonoff	TDX Corp.

Initial experimental results for the model were reported in WES Technical Report CERC-96-7, "Study of Harbor Improvements at St. Paul Harbor, St. Paul Island, Alaska," dated September 1996. Experimental results for the reactivated model regarding flushing of Salt Lagoon and small-boat harbor improvements are reported herein.

Dr. Robert W. Whalin was Director of WES during model experimentation and the preparation and publication of this report. COL Bruce K. Howard, EN, was Commander.

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4046.873	square meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers
square feet	0.09290304	square meters
square miles (U.S. statute)	2.589988	square kilometers
tons (2,000 lb, mass)	907.1848	kilograms

1 Introduction

Prototype

St. Paul Island is the northernmost and largest island of the Pribilofs in the eastern Bering Sea (Figure 1) with a land area of 114 sq km (44 sq miles).[1] The

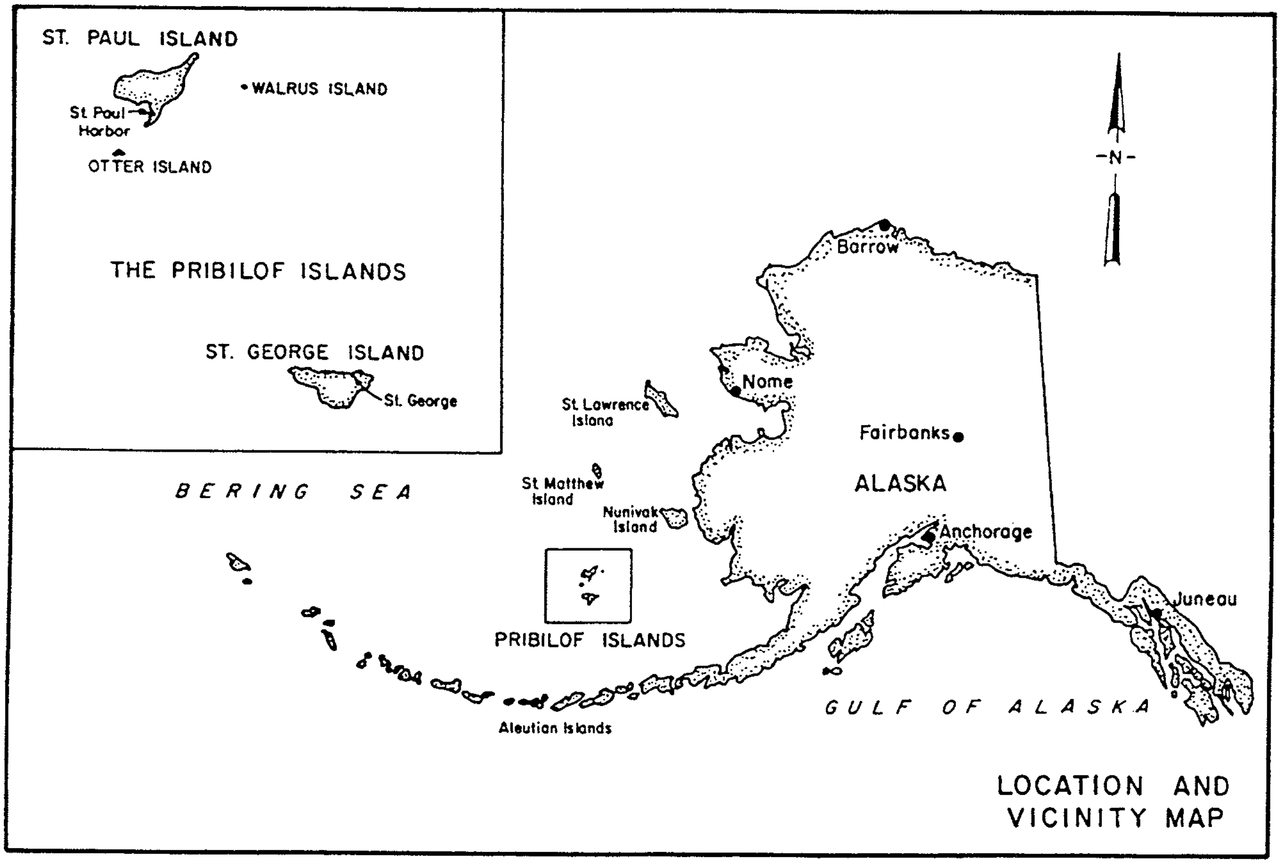

Figure 1. Project location

[1] Units of measurement in this report are shown in SI (metric) units, followed by non-SI (British) units in parentheses. In addition, a table of factors for converting non-SI units of measurement used in figures, plates, and tables in this report to SI units is presented on page vi.

Pribilofs are of volcanic origin, and St. Paul Island is composed predominantly of volcanic materials in the form of lava flows and loose cinders with sandy deposits. The west and southwest portions of the island are relatively high and mountainous with precipitous cliffs along the coast. The remainder of the island is relatively low and rolling with a number of extinct volcanic peaks scattered throughout. Only two of the Pribilof Islands are populated, St. Paul with about 800 people and St. George with approximately 300 residents. Two-thirds of the St. Paul population is Alaska Native.

The Pribilof Islands support large populations of birds, mammals, fish, and invertebrates. The Pribilofs are the primary breeding ground for northern fur seals, where approximately two-thirds of the world's population (1.3 to 1.4 million) migrate annually (U.S. Army Engineer District (USAED), Alaska 1981). More than a quarter million seabirds nest on St. Paul Island each year, mainly along the coastal cliffs. The uplands are inhabited by song birds, white and blue foxes, and a transplanted herd of approximately 250 reindeer. The island is treeless and covered with grasses, sedges, and wildflowers. The eastern Bering Sea near St. Paul supports populations of shrimp, commercially harvestable species of crab, and bottom fish.

The city of St. Paul is located on a cove on the southern tip of the island and is the island's only settlement. The islands were originally settled by the Russians to harvest fur seals. The treaty for the purchase of Alaska from Russia by the United States in 1867 placed the Pribilofs under United States control. The National Marine Fisheries Service (NMFS) and its predecessor Federal agencies were responsible for the fur seal industry in the Pribilofs since 1911, managing the harvest according to a series of international agreements between the United States, Canada, Japan, and the Soviet Union. In 1983, the harvest of fur seals was discontinued due to a seal harvest moratorium. The NMFS terminated administration, management, and employment at St. Paul. This event had a significant adverse impact on the economy, and the standard of living could not be maintained. At that time the village had no other economic base, no harbor infrastructure, inadequate and unpermitted utilities, overcrowded housing, high unemployment, and limited air and vessel transportation. Development of a harbor, and associated marine-related industries, fulfilled the need for new sources of employment and income on the island.

Harbor Development

A breakwater was constructed at St. Paul in Village Cove during 1983, but subsequently failed during the storms of 1984. A new breakwater was designed and constructed by Tetra Tech, Inc., consultants to the City of St. Paul (Tetra Tech, Inc. 1987). The structure was 229 m (750 ft) in length and functioned well, in regard to stability, during the 1985 and 1986 winter seasons. A 61-m-long (200-ft-long), vertical-wall dock was installed in the lee of the breakwater in 1986 to accommodate fishing vessels. The breakwater, however, was not of sufficient length to provide wave protection to vessels using the dock, particularly during storm events.

In 1989, construction of the current harbor was completed. It consists of a 549-m-long (1,800-ft-long) main breakwater, a 296-m-long (970-ft-long) detached breakwater, and space for 274 m (900 ft) of docks on the lee side of the main breakwater. The main breakwater, generally, follows the -7.6-m (-25-ft)[1] contour in Village Cove and results in a harbor with 32,375 to 40,470 sq m (8 to 10 acres) of area and water depths of 5.5 to 7.6 m (18 to 25 ft) on the lee side of the breakwater. The center line of the detached breakwater makes an interior angle of 75 deg with the main structure at sta 17+00, and provides a 91-m-wide (300-ft-wide) harbor entrance. A 61-m-wide (200-ft-wide) opening between the eastern end of the detached breakwater and the shore is maintained to enhance harbor circulation. An aerial photograph of the existing St. Paul Harbor is shown in Figure 2.

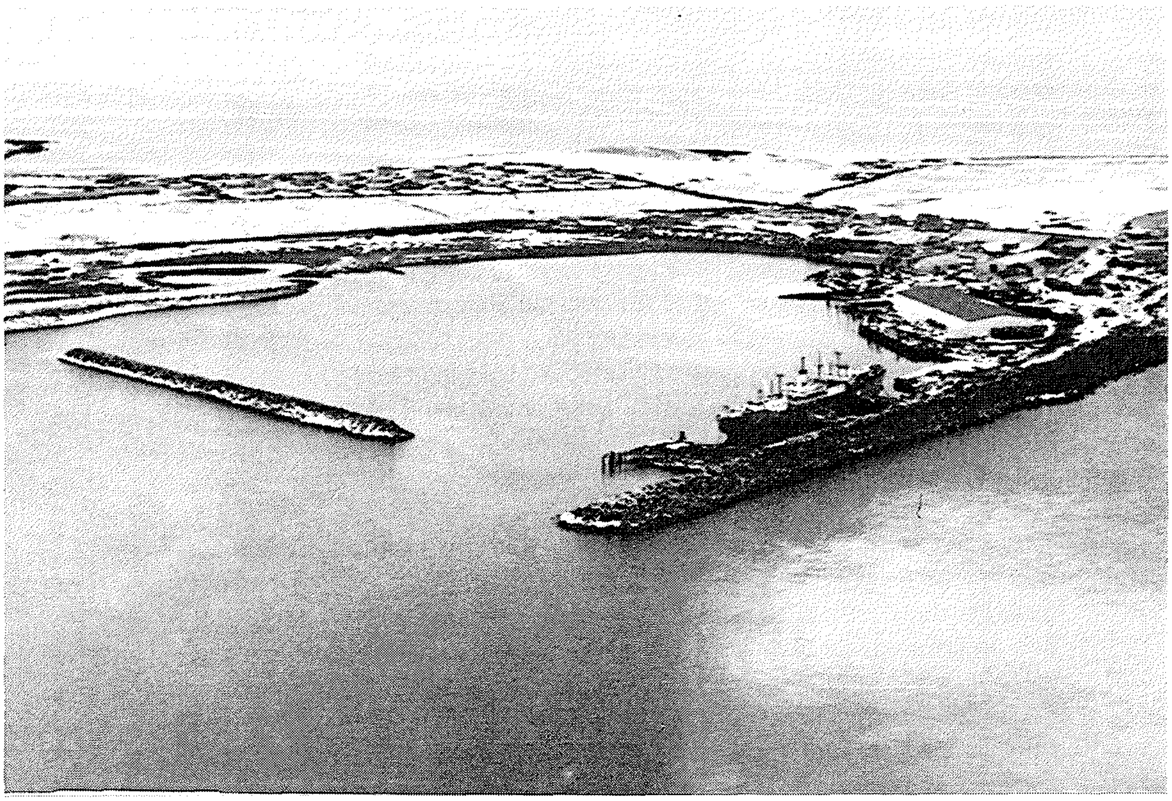

Figure 2. Aerial photograph of St. Paul Harbor

The main breakwater has a crest elevation (el) of +11.3 m (+37 ft) from sta 7+50 to a point approximately 15.2 m (50 ft) north of the northernmost dock. The remaining portion of the structure has a crest el of +9.1 m (+30 ft). Armor stone used on the breakwater trunk was 16,330 kg (18 ton), and 21,770-kg (24-ton) armor stone was used on the head. The slope of the trunk is 1V:2H with a 1V:3H slope around the breakwater head. A roadway was constructed on the lee side of the main breakwater adjacent to the proposed docks. The detached breakwater has a crest el of +5.5 m (+18 ft) with 4,535-kg (5-ton) armor stone placed on a slope of

[1] All contours and elevations cited herein are in meters (feet) referred to mean lower low water (mllw) unless otherwise noted.

1V:1.5H. Prior to construction of the 1989 improvements, both two-dimensional (Ward 1988) and three-dimensional (Bottin and Mize 1988) hydraulic model investigations were conducted at the U.S. Army Engineer Waterways Experiment Station (WES) to optimize structural and functional design of the harbor.

Problems and Needs

When constructed in 1989, St. Paul Harbor was designed to support a fishing fleet one-third the size of the current operating fleet. It was not intended that the harbor have floating or shore-based processing plants. It was designed only to accommodate unladen fishing vessels going into the harbor to refuel and stock provisions. Large loaded vessels were not expected to use the harbor because processing facilities were located outside the harbor. The design vessel was 33.5 m (110 ft) in length and drafted 3.7 m (12 ft) unladen.

St. Paul Harbor currently serves a fleet of 230 transient vessels during the crabbing season. In 1994, a total of 27 floating processors were located within a 4.8-km (3-mile) limit of the harbor. St. Paul is in a rapid growth cycle. Established seafood processors are investing capital to relocate and build processing plants there. Unisea moved a floating crab processing plant from Dutch Harbor to the city dock, and Icicle Seafoods has moored a processor to the local Native corporation dock. In the harbor, Unipak has established two onshore plants. The Unipak plants are capable of processing halibut, cod, and pollock in addition to crab, opening the possibility of expanded fisheries processing in the area (USAED, Alaska 1995).

When more than one vessel in the harbor needs fuel, waiting can last for several hours at the fuel dock. During the crabbing season, the fuel dock is closed a minimum of 3 hr at least once each week when cargo vessels deliver supplies to the harbor. In addition, the harbor must be closed at random intervals due to weather. Due to the lack of a turning basin, smaller fishing vessels are forced to move to accommodate larger vessels when the harbor is crowded or when large ships are in port. Limited space makes it difficult for vessels to enter and depart the harbor, resulting in substantial delays.

Large vessels and processors operating in the eastern Bering Sea travel to Dutch Harbor to deliver their catches due to the lack of room and shallow draft in St. Paul Harbor. Dutch Harbor is farther from the fishing grounds than St. Paul. Some vessel operators have indicated that if the harbor were deeper and had a turning basin, they would unload their catches at St. Paul to save fuel and travel time. Vessels in distress also have been towed to Dutch Harbor from the fishing grounds because there is no place for them to tie up at St. Paul without impacting the already congested harbor. Fishermen injured due to accidents are taken to the St. Paul Clinic for treatment. Vessels in the harbor are sometimes forced to move to allow the entrance of a vessel in distress or a vessel dropping off injured fishermen.

Previously Reported Model Experiments and Conclusions

The St. Paul Harbor model was constructed initially to investigate the feasibility of deepening the entrance channel and dredging a deeper and larger maneuvering basin to relieve the current congestion. The impacts of proposed harbor improvements on wave conditions, wave-induced current patterns and magnitudes, and sediment patterns and subsequent deposits in the harbor were studied. In addition, the impacts of proposed submerged reef breakwaters were investigated relative to wave-induced current patterns and magnitudes and sediment tracer patterns and subsequent deposits seaward of the main breakwater. Details of the investigation were published (Bottin 1996), and conclusions derived from results of those experiments are shown below. Plan numbers refer to those in the initial investigation.

a. During periods of severe storm wave activity with high tide conditions, wave heights in the existing harbor will exceed 1.7 m (5.5 ft) along the dock in the lee of the main breakwater and 0.8 m (2.5 ft) at the Tanadgusix Corporation (TDX) dock.

b. For existing conditions, currents enter the harbor through the opening at the shoreward end of the detached breakwater and move in a clockwise direction, exiting through the entrance. Maximum velocities along the shoreline inside the harbor will exceed 2.5 mps (8 fps). Currents also move seaward along the seaside of the detached breakwater across the harbor entrance.

c. For existing conditions, sediment moves southerly along the boulder spit and enters the harbor through the opening at the shoreward end of the detached breakwater. Sediment also moves westerly along the seaside of the detached breakwater toward the harbor entrance.

d. Experimental results obtained for the initial submerged reefs (Plans 1 and 2) indicated the structures would have no adverse impact on current patterns and magnitudes or sediment tracer patterns and deposits seaward of the main breakwater.

e. An extension of the initial submerged reefs northerly by 122 m (400 ft) in length (Plan 4) will decrease wave heights in the approach and entrance channels and result in improved navigation conditions.

f. A 15.2-m (50-ft) reduction in the length of the submerged reefs (from 396 to 381 m (1,300 to 1,250 ft)) on their southern end (Plan 9) will not increase wave conditions in the harbor.

g. Experimental results for the deepened channel and maneuvering area and the 381-m-long (1,250-ft-long) submerged reefs of Plan 10 indicated that wave heights would increase at the TDX dock and the inner harbor area when compared to existing conditions.

h. Installation of the wave-dissipating spending beach in the harbor (Plan 11) with the deepened channel and maneuvering area and the 381-m-long (1,250-ft-long) submerged reefs will result in reduced wave conditions. Wave heights throughout the harbor will be significantly less than those obtained for existing conditions.

i. Installation of Plan 10 (deepened channel and maneuvering area and the 381-m-long (1,250-ft-long) submerged reefs) or Plan 11 (addition of the wave-dissipating spending beach) will have no adverse impact on current patterns and magnitudes and/or sediment patterns and subsequent deposits in the vicinity of the harbor.

Purpose of the Current Investigation

At the request of the U.S. Army Engineer District, Alaska (NPA), the hydraulic model of St. Paul Harbor was reactivated by WES to study both wave-induced circulation and tidal flushing of Salt Lagoon. In addition, experiments were conducted to to determine the impacts of proposed small-boat harbor modifications on wave conditions, current patterns and magnitudes, and sediment movement patterns and subsequent deposits within the complex. An expedited testing program was performed with a minimum number of experimental conditions. The study plan determined optimum during the initial investigation (Plan 11) was installed in the model during all experiments reported herein.

2 The Model

Design of Model

The St. Paul Harbor model (Figure 3) was constructed to an undistorted linear scale of 1:100, model to prototype. Scale selection was based on the following factors:

a. Depth of water required in the model to prevent excessive bottom friction.

b. Absolute size of model waves.

c. Available shelter dimensions and area required for model construction.

d. Efficiency of model operation.

e. Available wave-generating and wave-measuring equipment.

f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Model-Prototype Dimension[1]	Scale Relations
Length	L	$L_r = 1:100$
Area	L^2	$A_r = L_r^2 = 1:10,000$
Volume	L^3	$V_r = L_r^3 = 1:1,000,000$
Time	T	$T_r = L_r^{1/2} = 1:10$
Velocity	L/T	$V_r = L_r^{1/2} = 1:10$

[1] Dimensions are in terms of length (L) and time (T).

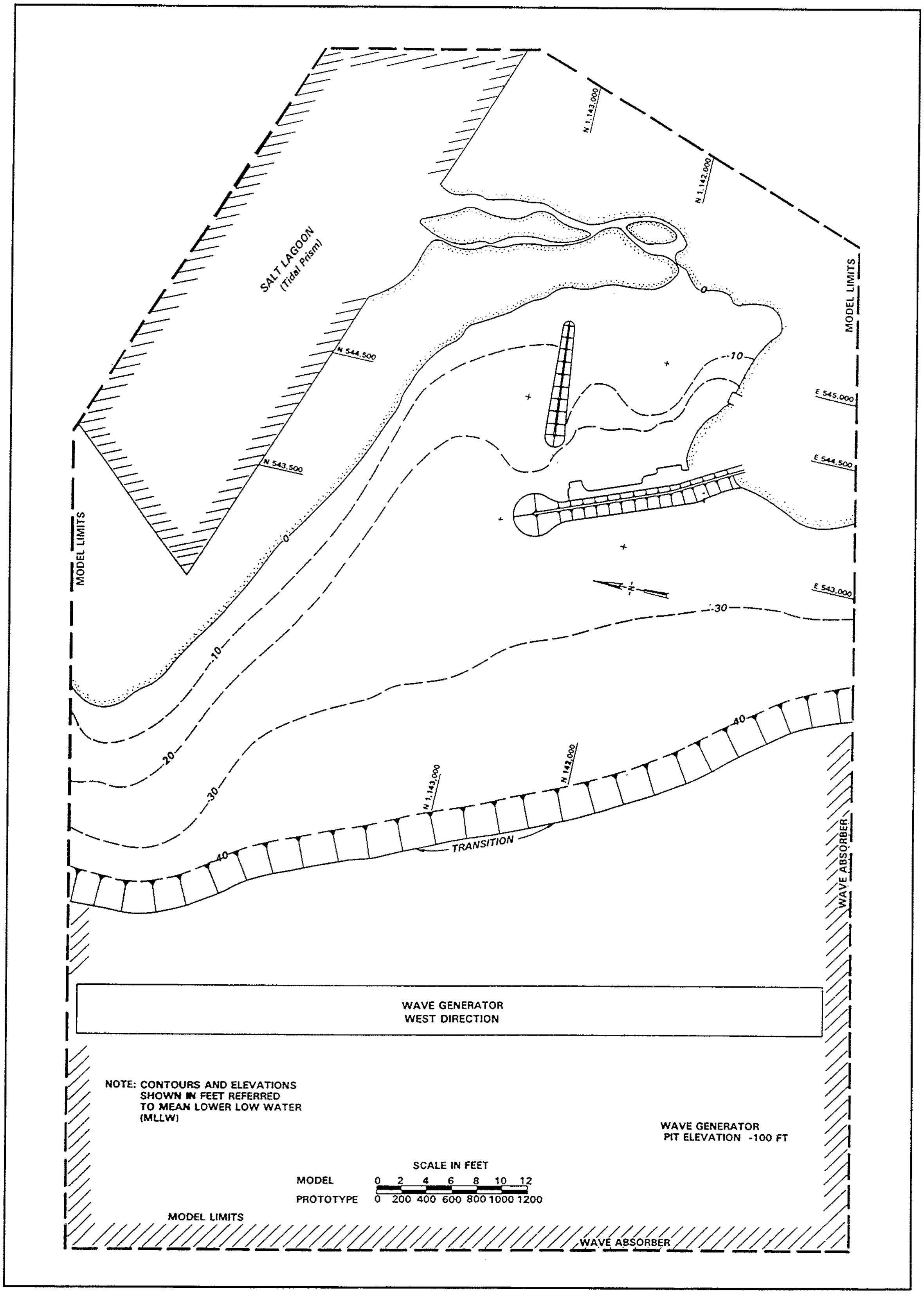

Figure 3. Model layout

The existing breakwaters and proposed reef breakwaters at St. Paul Harbor are rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus, the transmission and absorption of wave energy became a matter of concern in the design of the 1:100-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (LeMehaute 1965). Also, the transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations (Dai and Jackson 1966, Brasfeild and Ball 1967) at WES, this adjustment was made by determining wave-energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A cross section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission and reflection of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at St. Paul Harbor, it was determined that a close approximation of the correct wave-energy transmission and reflection characteristics could be obtained by increasing the size of the rock used in the 1:100-scale model to approximately two times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the St. Paul Harbor model, rock sizes were computed linearly by scale, then multiplied by 2 to determine the actual sizes to be used in the model.

Ideally, a quantitative, three-dimensional, movable-bed model investigation would best determine the impacts of harbor modifications with regard to sediment deposition in the vicinity of the harbor. However, this type of model investigation is difficult and expensive to conduct, and each area in which such an investigation is contemplated must be carefully analyzed. In view of the complexities involved in conducting movable-bed model studies and due to limited funds and time for the St. Paul Harbor project, the model was molded in cement mortar (fixed-bed), and a tracer material was obtained to qualitatively determine sediment patterns in the vicinity of the harbor.

Model and Appurtenances

The model reproduced approximately 2,865 m (9,400 ft) of the St. Paul Island shoreline (from Tolstoi Point easterly and then southerly to a point south of the existing breakwater trunk), the existing harbor, and underwater topography in the Bering Sea to an offshore depth of 12.2 m (40 ft) with a sloping transition to the wave generation pit elevation of -30.5 m (-100 ft). A small connecting channel to a salt lagoon (located east of the harbor) also was included in the model as well as the tidal prism of the salt lagoon. The total area reproduced in the model was approximately 605 sq m (6,500 sq ft), representing about 6 sq km (2.3 sq miles) in the prototype. Vertical control for model construction was based on mean lower low water (mllw) datum, and horizontal control was referenced to a local prototype grid system. A general view of the model is shown in Figure 4.

Model waves were reproduced by an 18.3-m-long (60-ft-long), electrohydraulic, unidirectional, spectral wave generator with a trapezoidal-shaped plunger. The vertical motion of the plunger was controlled by a computer-generated command signal, and movement of the plunger caused a displacement of water which generated required test waves.

An Automated Data Acquisition and Control System, designed and constructed at WES, was used to generate and transmit wave generator control signals, monitor wave generator feedback, and secure and analyze wave data at selected locations in the model. Through the use of a microvax computer, the electrical output of parallel-wire, capacitance-type wave gauges, which varied with the change in water-surface elevation with respect to time, were recorded on magnetic disks. These data then were analyzed to obtain the parametric wave data.

A 0.6-m (2-ft) (horizontal) solid layer of fiber wave absorber was placed along the inside perimeter of the model to dampen wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

The St. Paul Harbor model facility did not include calibrated tidal reproduction facilities. These facilities require an enormous amount of time and funds to prepare. Since time and funds were limited, model tides were reproduced simply by raising (filling the basin) or lowering (draining the basin) the water level. The water level was raised and lowered linearly over the appropriate tidal period (36 min in the model, which equates to 6 hr in the prototype).

Design of Tracer Material

As discussed previously, a fixed-bed model was constructed and a tracer material selected to qualitatively determine movement patterns and deposition of sediment in the vicinity of the harbor. Tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation, or model law, among the four basic scale ratios, i.e., the horizontal scale λ; the vertical scale μ; the sediment size ratio η_D; and the relative specific weight ratio η_γ. These relations were determined experimentally using a wide range of wave conditions and bottom materials and are valid mainly for the breaker zone.

Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:100 (model-to-prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of St. Paul Harbor was undistorted to allow accurate reproduction of short-period wave and current patterns, the following procedure (which has been successfully used and validated for undistorted models) was used to select a tracer material. Using the

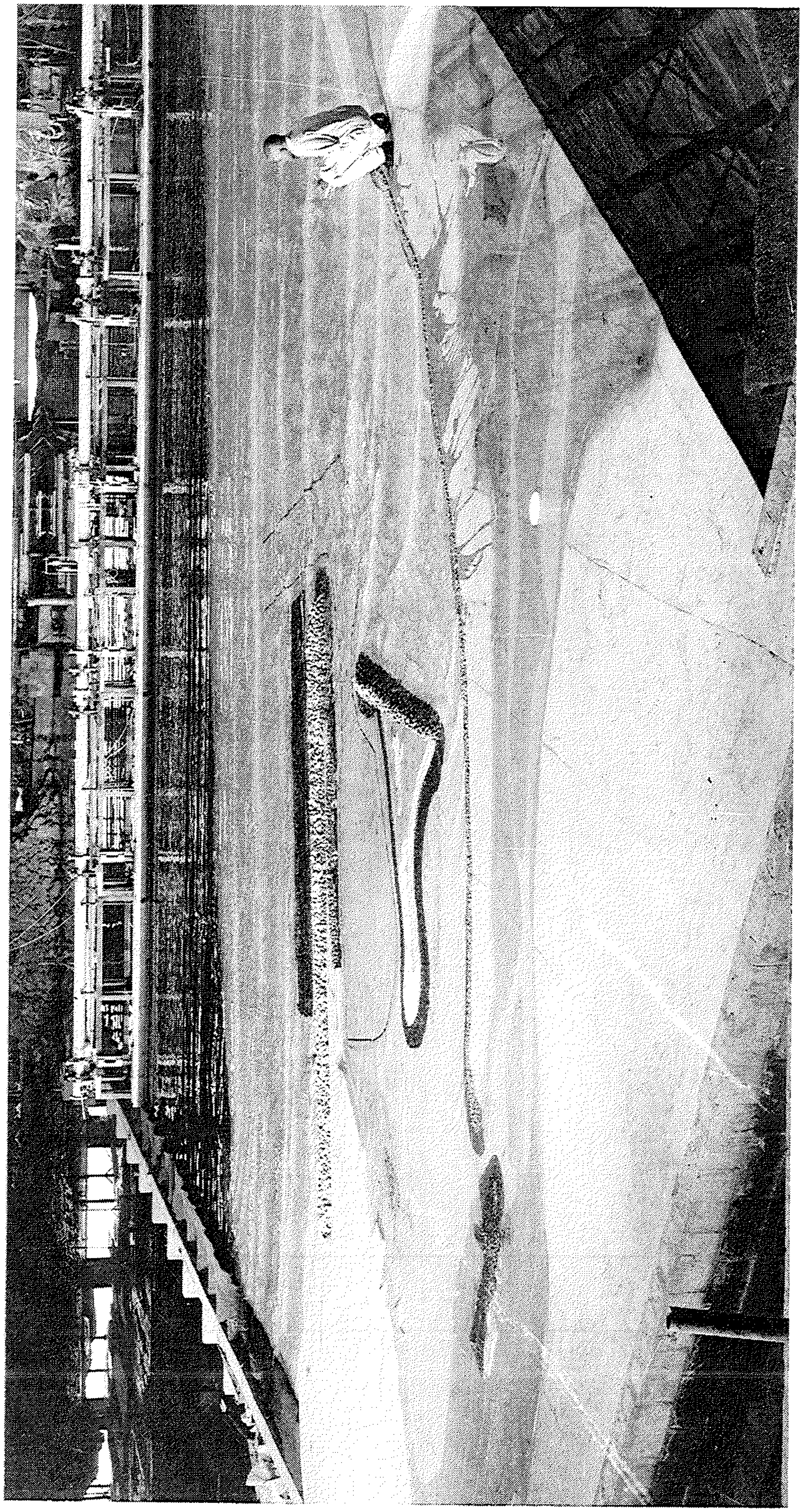

Figure 4. General view of model

prototype sand characteristics (median diameter, D_{50} = 0.19 mm, specific gravity = 2.82) and assuming the horizontal scale to be in similitude (i.e., 1:100), the median diameter for a given specific gravity tracer material and the vertical scale were computed. The vertical scale was then assumed to be in similitude and the tracer median diameter and horizontal scale were computed. This resulted in a range of tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that crushed coal tracer more nearly represented the movement of prototype sand. Therefore, quantities of crushed coal (specific gravity = 1.30; median diameter, D_{50} = 0.42 - 0.59 mm) were selected for use as a tracer material throughout the model investigation.

3 Experimental Conditions and Procedures

Selection of Experimental Conditions

Still-water level

Still-water levels (swl's) for wave action models are selected so that various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include refraction of waves in the project area, overtopping of harbor structures by waves, reflection of wave energy from various structures, and transmission of wave energy through porous structures.

In most cases, it is desirable to select a model swl that closely approximates the higher water stages which normally occur in the prototype, for the following reasons:

a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.

b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind, tide, and storm surge.

c. Selection of a high swl helps minimize model scale effects due to viscous bottom friction.

d. When a high swl is selected, a model investigation tends to yield more conservative results.

Swl's of +1.0, +1.5, and +2.1 m (+3.2, +5.0, and +7.0 ft) were selected by NPA for use during the initial experiments with the St. Paul model. Only the +1.0- and +2.1-m (+3.2- and +7.0-ft) swl's, however, were used during this experimental series. The lower value (+1.0 m (+3.2 ft)) represents mean higher high water and was used while obtaining wave heights, wave-induced current pattern and magnitudes, and sediment tracer patterns and subsequent deposits in the harbor. The higher value (+2.1 m (+7.0 ft)) was used while securing wave height data in the harbor. This value was estimated at the harbor based on observations made in the prototype during storm wave conditions. Both swl's were used for tidal flushing experiments.

Factors influencing selection of experimental wave characteristics

In planning the experimental program for a model investigation of harbor wave-action problems, it is necessary to select heights, periods, and directions for the test waves that will allow a realistic test of the proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum significant wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed continues to blow, and the distance over water (fetch) which the wind blows. Selection of experimental wave conditions entails evaluation of such factors as:

a. Fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can approach the problem area.

b. Frequency of occurrence and duration of storm winds from the different directions.

c. Alignment, size, and relative geographic position of the navigation structures.

d. Alignments, lengths, and locations of the various reflecting surfaces in the area.

e. Refraction of waves caused by differentials in depth in the area seaward of the site, which may create either a concentration or a diffusion of wave energy.

Wave refraction

When waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to selection of experimental wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. During a previous model investigation (Bottin and Mize 1988), the change in wave height and direction at St. Paul Harbor was determined by using the numerical Regional Coastal Processes Wave Transformation Model developed by Ebersole (1985). During the previous study, model experiments were conducted for five wave directions. For the current series, however, waves from only the west (259 deg) direction were used. The west direction was the most critical with respect to wave heights, wave-induced current patterns and magnitudes, and sediment tracer patterns at the harbor.

Prototype wave data and selection of experimental waves

Measured prototype data covering a sufficiently long duration from which to base a comprehensive statistical analysis of wave conditions were unavailable for the St. Paul Harbor area. However, in the previous model investigation (Bottin and Mize 1988), statistical deepwater wave hindcast data representative of this area were obtained from the Coastal Engineering Research Center (CERC) Wave Information Studies (WIS). Additional information on WIS may be obtained from Corson (1985). After a review of the data from the previous study, and due to limited time and funds for the current investigation, NPA selected the following waves for use in the current experimental series:

Period, sec	Height, m (ft)
8	3.0 (10)
10	3.0 (10)
16	4.4 (14.4)
16	5.8 (19)
20	4.3 (14)

Unidirectional wave spectra were generated based on Joint North Sea Wave Project parameters for the selected waves and used throughout the model investigation. Selected waves were defined as significant wave height, the average height of the highest one-third of the waves, or H_s. In deepwater, H_s is very similar to H_{mo} (energy-based wave) where $H_{mo} = 4\ (E)^{1/2}$, and E equals total energy in the spectra, which is obtained by integrating the energy density spectra over the frequency range.

Analysis of Model Data

Relative merits of the various plans were evaluated by:

a. Comparison of wave heights at selected locations in the model.

b. Comparison of wave-induced current patterns and magnitudes.

c. Comparison of sediment tracer movement and subsequent deposits.

d. Comparison of tidal els and flows.

e. Visual observations and wave pattern photographs.

In the wave-height data analysis, the average height of the highest one-third of the waves (H_s), recorded at each gauge location, was computed. All wave heights then were adjusted by application of Keulegan's equation[1] to compensate for excessive model wave height attenuation due to viscous bottom friction. From this equation, reduction of model wave heights (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel and the model data can be corrected and converted to their prototype equivalents.

[1] G. H. Keulegan. (1950). "The gradual damping of a progressive oscillatory wave with distance in a prismatic rectangular channel," Unpublished data, National Bureau of Standards, Washington, DC, prepared at request of Director, WES, Vicksburg, MS, by letter of 2 May 1950.

4 Experiments and Results

Experiments

Twelve study plans were evaluated during the initial portion of this investigation (Bottin 1996); therefore, plan numbering for this experimental series began with Plan 13. Proposed improvement plans for this experimental series consisted of dredging a new channel, boat basins, and a sediment deposition basin as well as installation of breakwaters in the existing harbor. Modifications also were made to the existing shoreline and to the existing connecting channel into Salt Lagoon, and new wave energy channels were installed entering Salt Lagoon north of the existing harbor. Experiments of tidal flushing were conducted with wave energy channels entering Salt Lagoon north of the harbor, and changes in the orientation of the existing connecting channel into the lagoon. Wave heights and wave-induced current patterns and magnitudes were obtained for variations in the harbor that consisted of changes in shoreline configurations and structure lengths and alignments. Study plans that consisted of shoreline changes in the harbor and changes of the orientation of the existing connecting channels were expeditiously constructed in the model using gravel to determine optimum layouts. Brief descriptions of the improvement plans are presented in the following subparagraphs, and dimensional details are shown in Plates 1-14.

a. Plan 13 (Plate 1) consisted of the installation of a 5.5-m-deep, 30.5-m-wide (18-ft-deep, 100-ft-wide) channel, a 5.5-m-deep (18-ft-deep) basin, a 3.7-m-deep (12-ft-deep) basin, a 3-m-deep (10-ft-deep) deposition basin, and a 0.9-m-deep (3-ft-deep) area east of the proposed boat basin. It also included a 106.7-m-long (350-ft-long) west breakwater and a 76.2-m-long (250-ft-long) detached north breakwater. Breakwater els were +3 m (+10 ft).

b. Plan 14 (Plate 2) included the elements of Plan 13 with a shoreline configuration installed through the 0.9-m-deep (3-ft-deep) area and a portion of the 3-m-deep (10-ft-deep) area east of the harbor basin. The Salt Lagoon connecting channel was formed to enter the harbor at its approximate current location.

c. Plan 15 (Plate 3) entailed the elements of Plan 14 with 21.3 m (70 ft) of length removed from the shoreward end of the west breakwater.

d. Plan 16 (Plate 4) involved the elements of Plan 14 with an 82.3-m-long (270-ft-long) breakwater installed that originated on the southern end of the wave-dissipating spending beach and extended southeasterly. The western 38.1-m-long (125-ft-long) portion of the north breakwater also was removed, resulting in a 38.1-m-long (125-ft-long) detached structure.

e. Plan 17 (Plate 5) consisted of the elements of Plan 16, but the north breakwater was moved 15.2 m (50 ft) easterly and reoriented parallel to the shoreline.

f. Plan 18 (Plate 6) involved the elements of Plan 17 with a 12.2-m-long (40-ft-long) extension of the breakwater extending from the spending beach.

g. Plan 19 (Plate 7) entailed the elements of Plan 18, but the shoreline east of the harbor basin was reoriented to represent historic conditions. The mouth of the Salt Lagoon channel was moved to a more southerly location and entered the harbor in the 3.7-m-deep (12-ft-deep) basin.

h. Plan 20 (Plate 8) included the elements of Plan 19 with a 60.1-m-wide (200-ft-wide) wave energy channel into Salt Lagoon. The channel was installed north of the existing harbor, and its elevation was +0.6 m (+2.0 ft).

i. Plan 21 (Plate 9) involved the elements of Plan 20, but the elevation of the wave energy channel was raised to +0.9 m (+3.0 ft).

j. Plan 22 (Plate 9) entailed the elements of Plan 20, but the elevation of the wave energy channel was raised to +1.2 m (+4.0 ft).

k. Plan 23 (Plate 10) involved the elements of Plan 21, but the width of the wave energy channel was decreased to 30.5 m (100 ft).

l. Plan 24 (Plate 11) consisted of the elements of Plan 18, but the shoreline east of the harbor basin and the connecting channel to Salt Lagoon were reoriented slightly. A berm (el +3 m (+10 ft)) was installed east of the harbor basins. The 3.7-m-deep (12-ft-deep) basin was decreased in width by 56.4 m (185 ft) with existing els installed, and the north breakwater was reduced in length to 30.5 m (100 ft) and reoriented in a northwesterly direction. The breakwater extending from the spending beach was replaced by expanding the spending beach in a southeasterly direction. This configuration represents a 26-vessel boat basin.

m. Plan 25 (Plate 12) included the elements of Plan 24, but the 3.7-m-deep (12-ft-deep) basin was expanded to its original width and the north breakwater was reoriented 15.2 m (50 ft) southeasterly. This configuration represents a 52-vessel boat basin.

n. Plan 26 (Plate 13) consisted of the elements of Plan 24, but the small-boat entrance channel and basins were filled in to existing depths and the west breakwater was removed.

o. Plan 27 (Plate 14) involved the elements of Plan 26, but an area west of the proposed west breakwater location was deepened to 5.5 m (18 ft).

Wave height experiments

Wave height experiments were conducted for various improvement plans with 8-, 16-, and/or 20-sec waves. Experiments involving some proposed plans were limited to 16-sec waves. Wave gauge locations are shown in referenced plates.

Wave-induced current patterns and magnitudes

Wave-induced current patterns and magnitudes were obtained for selected improvement plans for 8-, 16-, and 20-sec waves. These experiments were conducted by timing the progress of a dye tracer relative to a known distance on the model surface at selected locations in the model.

Sediment tracer experiments

Sediment tracer experiments were conducted for the most promising improvement plans using 8-, 16-, and 20-sec waves. Sediment tracer was introduced into the model along the shoreline northeast of the detached breakwater to determine sediment tracer patterns and subsequent deposits.

Water surface el and tidal flow experiments

Water surface el and tidal flow experiments were conducted for selected improvement plans to determine flushing action. Elevations were obtained with point gauges that were located in the harbor, in Salt Lagoon, and about half way up the connecting channel to the lagoon. Tidal current patterns and magnitudes were obtained with a dye tracer similarly to those obtained for wave-induced currents.

Experimental Results

In analyzing results, the relative merits of various improvement plans were based on measured wave heights, wave-induced current patterns and magnitudes, the movement of sediment tracer material and subsequent deposits, water surface els, and tidal flow currents. Model wave heights (significant wave heights or H_s) and tidal els were tabulated to show measured values at selected locations. Wave-induced and tidal current patterns and magnitudes were shown on plates, and sediment tracer patterns and subsequent deposits are presented in photographs.

Results of wave height experiments for Plans 13-18 are presented in Table 1 for waves with the +2.1-m (+7.0-ft) swl. Maximum wave heights[1] ranged from 0.49 to 0.64 m (1.6 to 2.1 ft) in the entrance channel (gauge 3), 0.24 to 0.27 m (0.8 to 0.9 ft) in the mooring basin (gauges 8, 10, and 11), and 0.52 to 0.73 m (1.7 to 2.4 ft) in the sediment deposition basin (gages 5, 6, and 9) for all the study plans. Wave heights at various gauge locations were similar for the same wave conditions (i.e., 16-sec, 5.8-m (19-ft) waves. Also, wave heights in the mooring areas were less than the established 0.3 m (1.0 ft) criterion for all the study plans.

Experiments conducted for Plans 13-18 were considered preliminary. Visual observations during preliminary experiments indicated that sediment moved into the harbor between the detached breakwater and the shoreline and migrated southerly, and then westerly, into the entrance channel. The installation of the breakwater extending southeasterly from the spending beach (Plan 16) was required to prevent shoaling of the entrance. The removal of the shoreward end of the west breakwater (Plan 15) only slightly increased wave heights at the gauge locations in the mooring areas; however, visual observations revealed increased activity along the shoreline inside the basin. Preliminary experiments also indicated that the location of the north breakwater was critical with respect to diverting tidal currents from the lagoon connecting channel toward the harbor basin and providing circulation.

Results of wave-induced water surface el experiments for Plans 19-23 are presented in Table 2 for 10-sec, 3-m (10-ft) and 16-sec, 5.8-m (19-ft) waves with the +1.0-m (+3.2-ft) and +2.1-m (+7.0-ft) swl's. Maximum differences in water surface els between the lagoon and the harbor were 0.09, 0.15, 0.18, 0.09, and 0.09 m (0.3, 0.5, 0.6, 0.3, and 0.3 ft) for Plans 19-23, respectively, for the +1.0-m (+3.2-ft) swl. With the +2.1-m (+7.0-ft) swl, maximum differences in water surface els between the lagoon and the harbor were 0.09, 0.43, 0.46, 0.27, and 0.27 m (0.3, 1.4, 1.5, 0.9, and 0.9 ft), respectively for Plans 19-23. These results indicated that the 61-m-wide (200-ft-wide), +0.9-m (+3.0-ft) channel was the optimum wave energy channel (Plan 21) with respect to flushing the lagoon.

Results of tidal water surface els obtained for Plan 19 are presented in Table 3. Results indicated a lag in the fluctuation of water surface els in the lagoon as opposed to that in the harbor. During ebb conditions, the harbor el dropped 0.94 m (3.1 ft) while the lagoon el fell only 0.4 m (1.3 ft). Likewise, during flood conditions, the harbor el increased 0.94 m (3.1 ft), while the lagoon increased only 0.37 m (1.2 ft).

Results of wave height experiments conducted for Plans 24 and 25 are presented in Table 4. For Plan 24 (26-vessel basin configuration), maximum wave heights were 0.52 m (1.7 ft) in the entrance channel (gauge 5), 0.27 m (0.9 ft) in the mooring area (gauges 8-10), and 0.67 m (2.2 ft) in the sediment deposition basin (gauge 11). Maximum wave heights were 0.52 m (1.7 ft) in the entrance channel, 0.21 m (0.7 ft) in the mooring area, and 0.64 m (2.1 ft) in the sediment deposition

[1] Refers to maximum significant wave heights throughout report.

basin for Plan 25 (52-vessel basin configuration). Wave heights for both plans were within the established 0.3-m (1.0-ft) criterion in the mooring areas.

Wave-induced current patterns and magnitudes obtained in the harbor for Plans 24 and 25 are presented in Plates 15-20 for representative waves with the +1.0-m (+3.2-ft) swl. Currents moved into the harbor through the opening between the shoreward end of the detached breakwater and the shoreline. Some tended to eddy in the sediment deposition basin due to the extension of the wave-dissipating spending beach. Other currents, generally, moved through the harbor in a clockwise manner and exited through the main entrance. Maximum velocities were 1.77 and 2.1 mps (5.8 and 6.9 fps) in the sediment deposition basin, 1.16 and 1.25 mps (3.8 and 4.1 fps) in the small-boat entrance channel, and 0.94 and 1.1 mps (3.1 and 3.6 fps) in the main entrance channel for Plans 24 and 25, respectively. Slight clockwise wave-induced current movement was noted in the mooring areas for both Plans 24 and 25. Visual observations of ebb tidal flows dictated the movement of the north breakwater between Plans 24 and 25. Movement of the structure was required to split tidal currents and allow for harbor basin flushing.

The general movement of tracer material and subsequent deposits for various waves for Plan 24 are shown in Figures 5-7. Tracer material was initially placed on the shoreline north of the harbor. It migrated into the deposition basin through the opening between the detached breakwater and the shoreline. Note the 8-sec, 3-ft (10-ft) waves moved very little material into the deposition basin. The 16-sec,

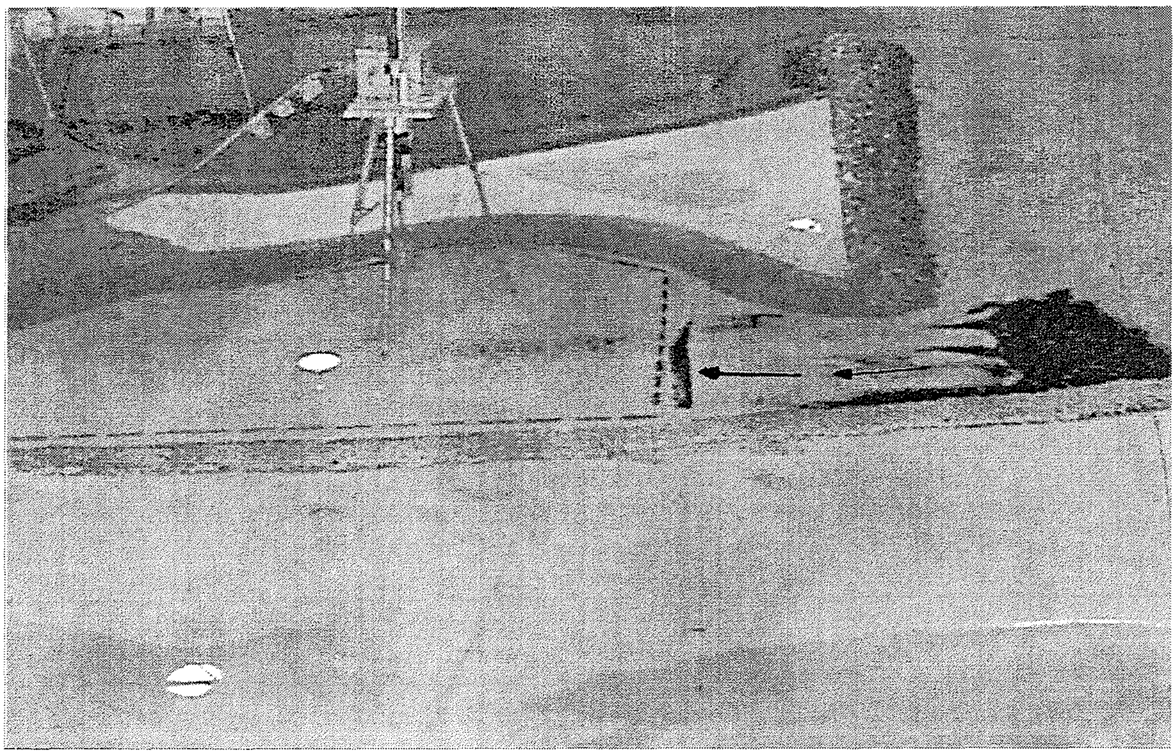

Figure 5. General movement of tracer material and subsequent deposits for Plan 24; 8-sec, 3-m (10-ft) waves

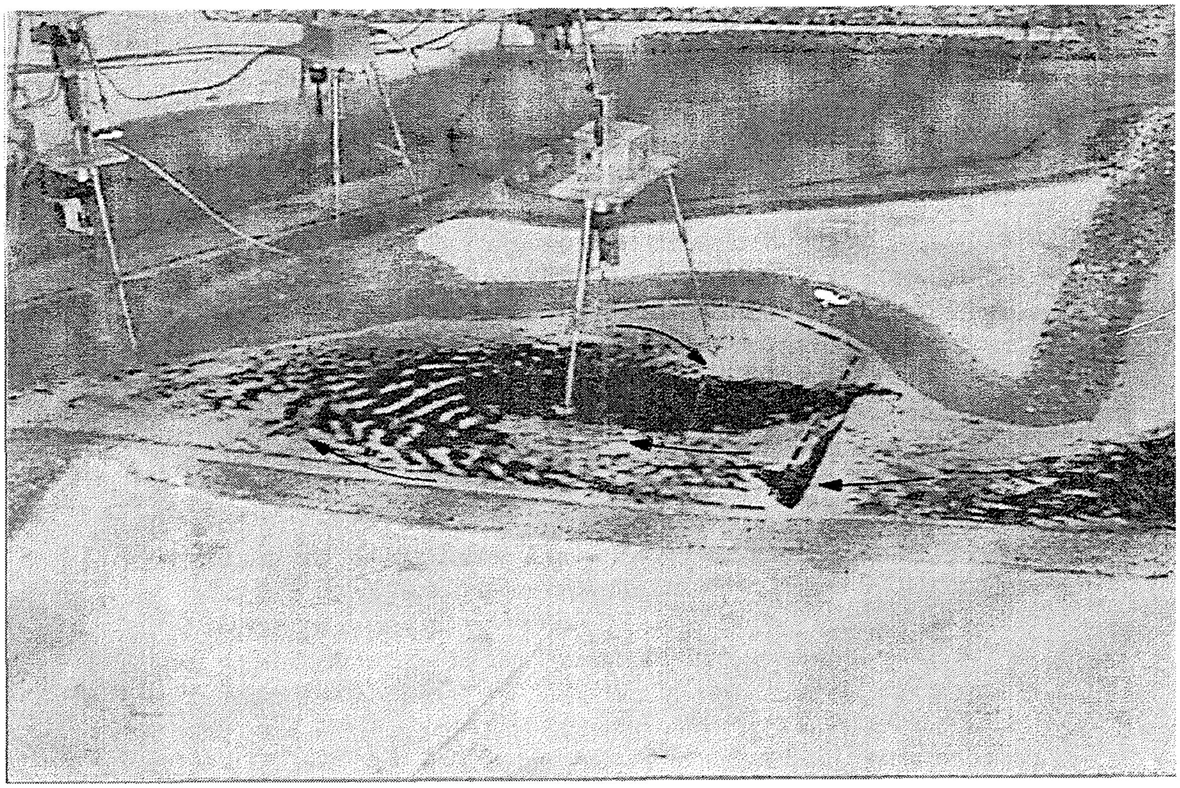

Figure 6. General movement of tracer material and subsequent deposits for Plan 24; 16-sec, 5.8-m (19-ft) waves

5.8-m (19-ft) and the 20-sec, 4.3-m (14-ft) waves, however, moved material into the deposition basin where it eddied in a clockwise manner and deposited. Sediment material did not move into the entrance channel or mooring areas for any of the experimental conditions. Results for Plan 25 were identical.

Wave-induced current patterns and magnitudes obtained for Plans 26 and 27 are presented in Plates 21-26 for representative waves with the +1.0-m (+3.2-ft) swl. Currents moved into the harbor through the opening between the shoreward end of the detached breakwater and the shoreline. Some tended to eddy in the sediment deposition basin, and some moved through the harbor in a clockwise manner and exited through the main entrance. Maximum velocities were 1.37 and 1.62 mps (4.5 and 5.3 fps) in the sediment deposition basin, 1.01 and 1.22 mps (3.3 and 4.2 fps) in the inner harbor area, and 2.04 and 1.58 mps (6.7 and 5.2 fps) in the main channel for Plans 26 and 27, respectively. Current magnitudes in the inner harbor were greater for Plans 26 and 27 in the vicinity of the proposed mooring basin than they were with the basin and west breakwater installed (Plans 24 and 25).

Ebb tidal current patterns and magnitudes secured for Plan 26 are shown in Plates 27 and 28 for tidal ranges of 1.0 and 2.1 m (3.2 and 7.0 ft), respectively. Most ebb tidal flow through the harbor area exited out the main entrance, while some exited the harbor between the detached breakwater and the boulder spit. Note that the north breakwater split the tidal flows. Magnitudes were measured at about the mid-range of the tidal cycles. Maximum velocities flowing out the connecting

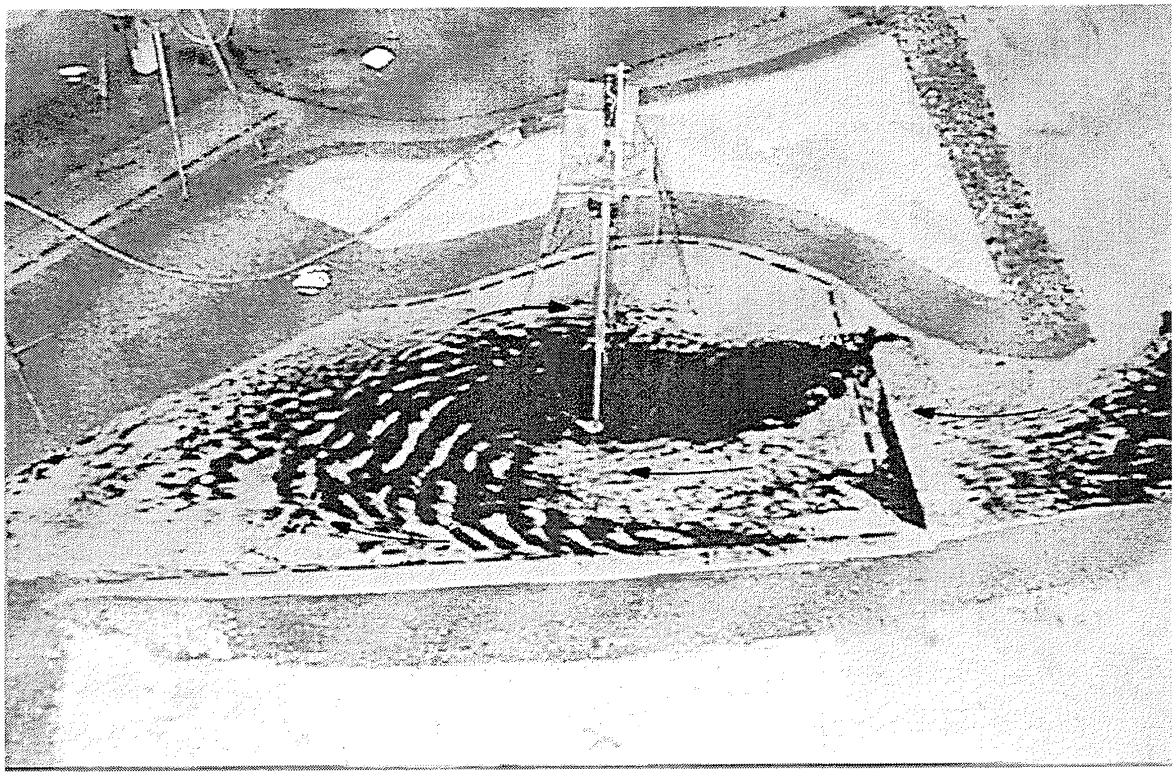

Figure 7. General movement of tracer material and subsequent deposits for Plan 24; 20-sec, 4.3-m (14-ft) waves

channel were 0.43 and 0.94 mps (1.4 and 3.1 fps), respectively, for the lower and higher tide ranges.

Based on test results for Plan 26, circulation conditions would be improved in the harbor with the installation of the north breakwater even if the small-boat harbor basins are not constructed. The sediment deposition basin and the extension of the wave-dissipating spending beach in a southeasterly direction also would improve shoaling conditions in the existing harbor based on results obtained.

5 Conclusions

Based on results of the coastal model investigation reported herein, it is concluded that:

a. Preliminary experiments (Plans 13-18) revealed that all improvement plans would result in wave heights of less than 0.3 m (1.0 ft) in the small-boat mooring areas.

b. Preliminary experiments indicated that with the originally proposed plans, sediment deposits would occur in the small-boat navigation channel. A breakwater extending southeasterly from the wave-dissipating spending beach, or an extension of the spending beach, however, would prevent shoaling of the channel.

c. Preliminary experiments revealed that the location of the north breakwater was critical with respect to diverting tidal currents from the lagoon connecting channel toward the harbor basin and providing circulation.

d. Of the improvement plans investigated with the wave energy channel connected to Salt Lagoon north of the harbor, the 61-m-wide (200-ft-wide), +0.9-m (+3.0-ft) el channel of Plan 21 was optimum with respect to those configurations.

e. The improvement plan configurations of Plans 24 and 25 (26-vessel and 52-vessel basins, respectively) will provide adequate wave protection, shoaling protection, and harbor circulation for the new small-boat harbor.

f. Improvements in shoaling and circulation conditions for the existing harbor will be obtained with the installation of the sediment deposition basin, the southeasterly extension of the wave-dissipating spending beach, and the north breakwater (Plan 26).

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Table 1
Wave Heights, for Plans 13-18 (swl = +7.0 ft)

Wave		Wave Height at Indicated Gauge Location, ft										
Period (sec)	Height (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
Plan 13												
16	14.4	2.3	2.0	1.6	1.5	1.7	1.3	1.2	0.7	0.7	0.7	0.7
16	19	2.9	2.4	2.0	1.9	2.4	1.6	1.2	0.8	0.9	0.9	0.8
20	14	2.8	2.5	1.9	2.0	1.9	1.5	1.3	0.7	0.9	0.9	0.8
Plan 14												
16	19	2.9	2.5	1.9	2.0	2.3	1.6	1.2	0.7	0.7	0.7	0.8
Plan 15												
16	19	2.7	2.4	1.9	1.9	2.3	1.6	1.2	0.9	0.7	0.7	0.9
Plan 16												
16	19	3.0	2.8	2.1	1.8	2.2	1.4	1.4	0.6	0.7	0.7	0.8
Plan 17												
16	19	2.8	2.8	2.1	1.8	2.3	1.4	1.3	0.6	0.6	0.7	0.8
Plan 18												
16	19	2.9	2.8	2.1	1.8	2.2	1.4	1.3	0.6	0.6	0.8	0.8

Table 2
Water Surface Elevations in Lagoon, Channel, and Harbor for Plans 19-23

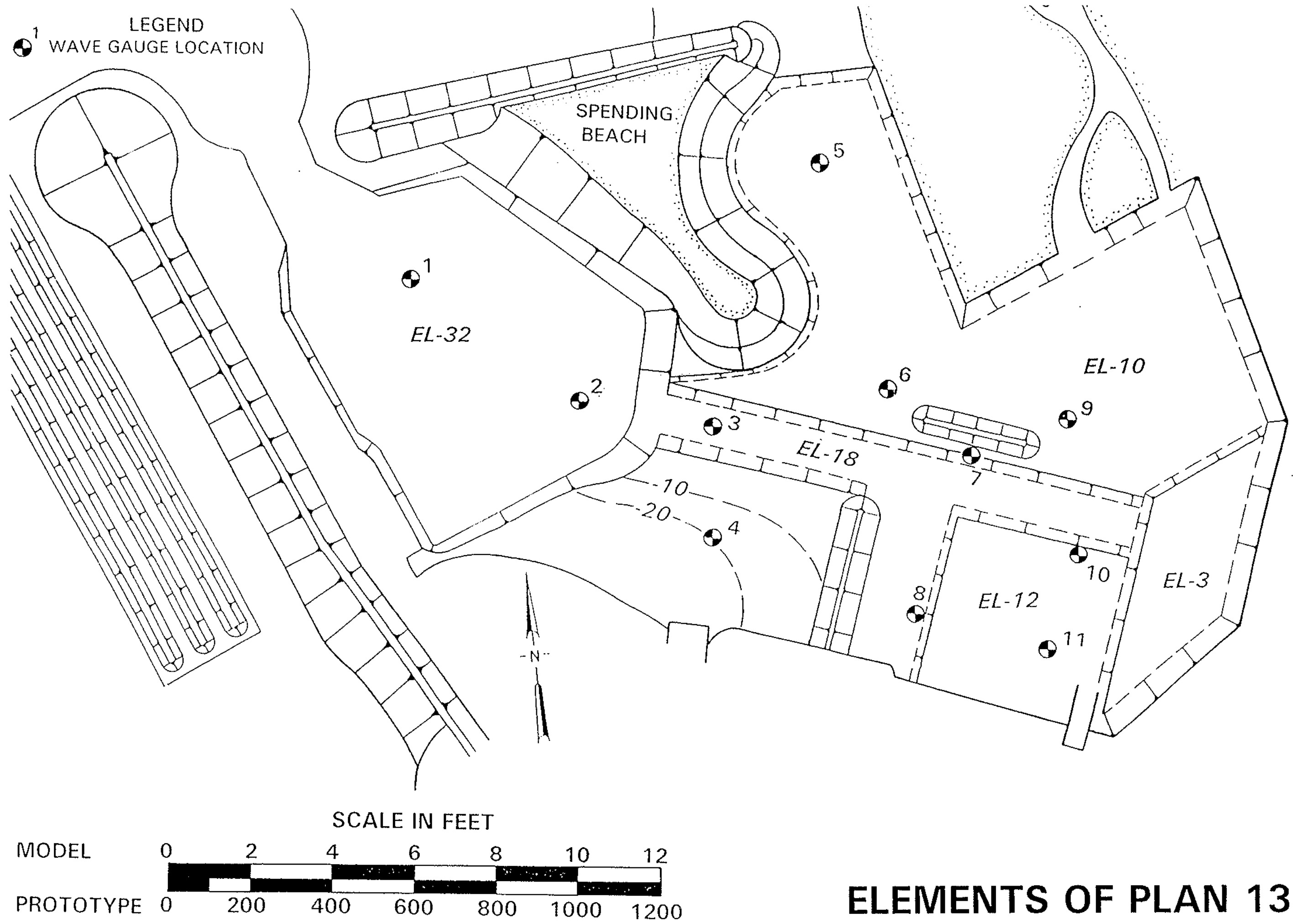
Wave		Water Surface Elevation, ft				
Period sec	Height ft	swl ft	Salt Lagoon	Channel	Harbor	Difference in Elevations Between Lagoon and Harbor
Plan 19						
10	10	+3.2	0.2	0.2	0.2	0
		+7.0	0.2	0.2	0.2	0
16	19	+3.2	0.6	0.4	0.3	0.3
		+7.0	0.8	0.7	0.5	0.3
Plan 20						
10	10	+3.2	0.5	0.4	0.2	0.3
		+7.0	1.9	1.5	0.5	1.4
16	19	+3.2	0.7	0.4	0.2	0.5
		+7.0	1.7	1.2	0.3	1.4
Plan 21						
10	10	+3.2	0.5	0.4	0.2	0.3
		+7.0	1.9	1.4	0.4	1.5
16	19	+3.2	0.7	0.6	0.1	0.6
		+7.0	1.8	1.5	0.4	1.4
Plan 22						
10	10	+3.2	-	-	-	-
		+7.0	1.2	0.9	0.3	0.8
16	19	+3.2	0.4	0.3	0.1	0.3
		+7.0	1.3	1.3	0.4	0.9
Plan 23						
10	10	+3.2	0.4	0.3	0.2	0.2
		+7.0	1.1	0.9	0.6	0.5
16	19	+3.2	0.5	0.4	0.2	0.3
		+7.0	1.5	1.4	0.6	0.9

Table 3
Tidal Elevations for Plan 19

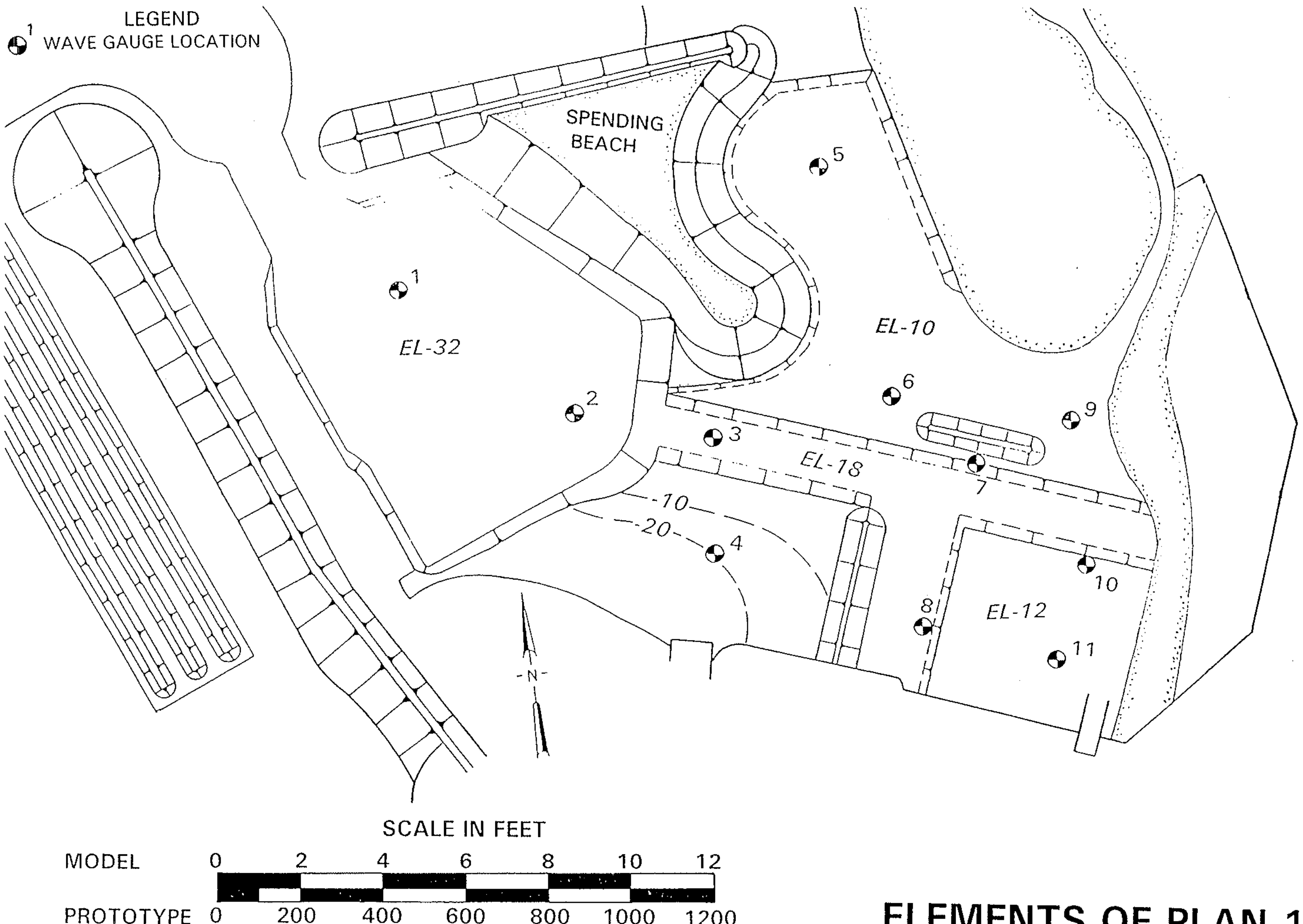
Model Time (min)	Tidal el, ft			
	Ebb Tide		Flood Tide	
	Harbor	Lagoon	Harbor	Lagoon
0.00	+3.2	+3.2	0.00	0.00
5	+2.7	+3.1	+0.6	+0.1
10	+2.4	+2.9	+1.0	+0.2
15	+1.8	+2.7	+1.4	+0.3
20	+1.4	+2.5	+1.7	+0.4
25	+1.0	+2.3	+2.1	+0.6
30	+0.5	+2.1	+2.8	+0.9
35	+0.1	+1.9	+3.1	+1.2

Table 4
Wave Heights for Plans 24 and 25

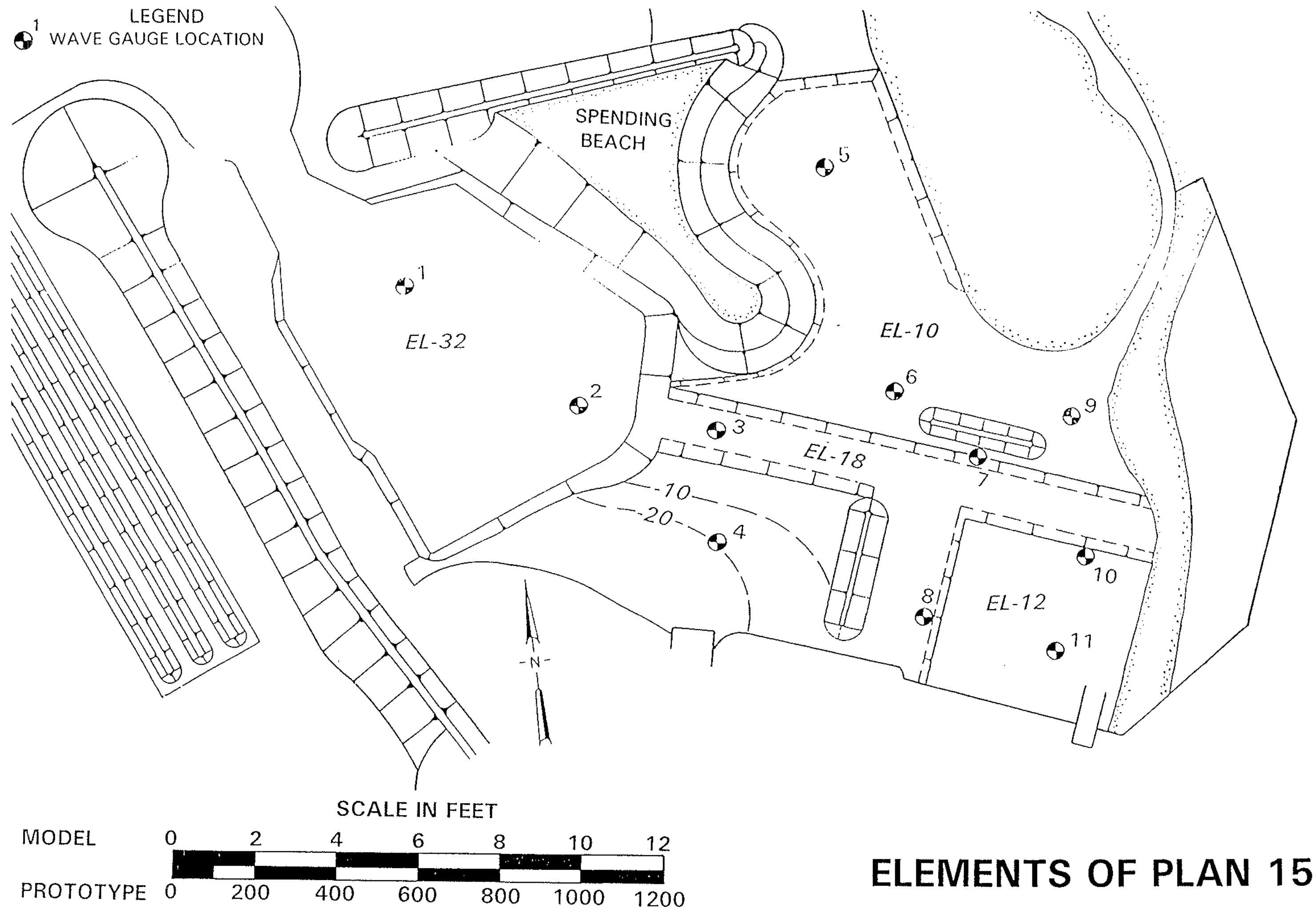
Wave		Wave Height at Indicated Gauge Location, ft										
Period sec	Height ft	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11
swl = +3.2 ft, Plan 24												
8	10	1.6	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.2	0.9
16	19	3.9	1.9	1.5	1.8	1.3	1.3	0.9	0.6	0.6	0.8	1.8
20	14	3.5	1.7	1.4	1.7	1.2	1.2	0.9	0.5	0.5	0.7	1.5
swl = +7.0 ft, Plan 24												
8	10	2.0	1.2	0.9	1.0	0.8	0.5	0.4	0.3	0.3	0.4	0.7
16	19	4.6	2.3	1.9	1.8	1.7	1.4	1.1	0.6	0.8	0.9	2.2
20	14	4.8	2.2	2.0	1.9	1.7	1.4	1.1	0.6	0.8	0.9	1.9
swl = +3.2 ft, Plan 25												
8	10	1.6	0.7	0.6	0.7	0.5	0.5	0.3	0.2	0.2	0.2	0.8
16	19	3.7	2.0	1.5	1.9	1.3	1.3	1.0	0.6	0.7	0.6	1.8
20	14	3.6	1.7	1.5	1.7	1.2	1.2	1.0	0.5	0.7	0.5	1.6
swl = +7.0 ft, Plan 25												
8	10	2.1	1.3	0.9	1.1	0.9	0.6	0.5	0.4	0.3	0.4	0.8
16	19	4.5	2.4	2.0	1.9	1.6	1.4	1.1	0.7	0.7	0.7	2.1
20	14	4.6	2.3	2.1	2.0	1.7	1.4	1.2	0.7	0.7	0.7	1.9



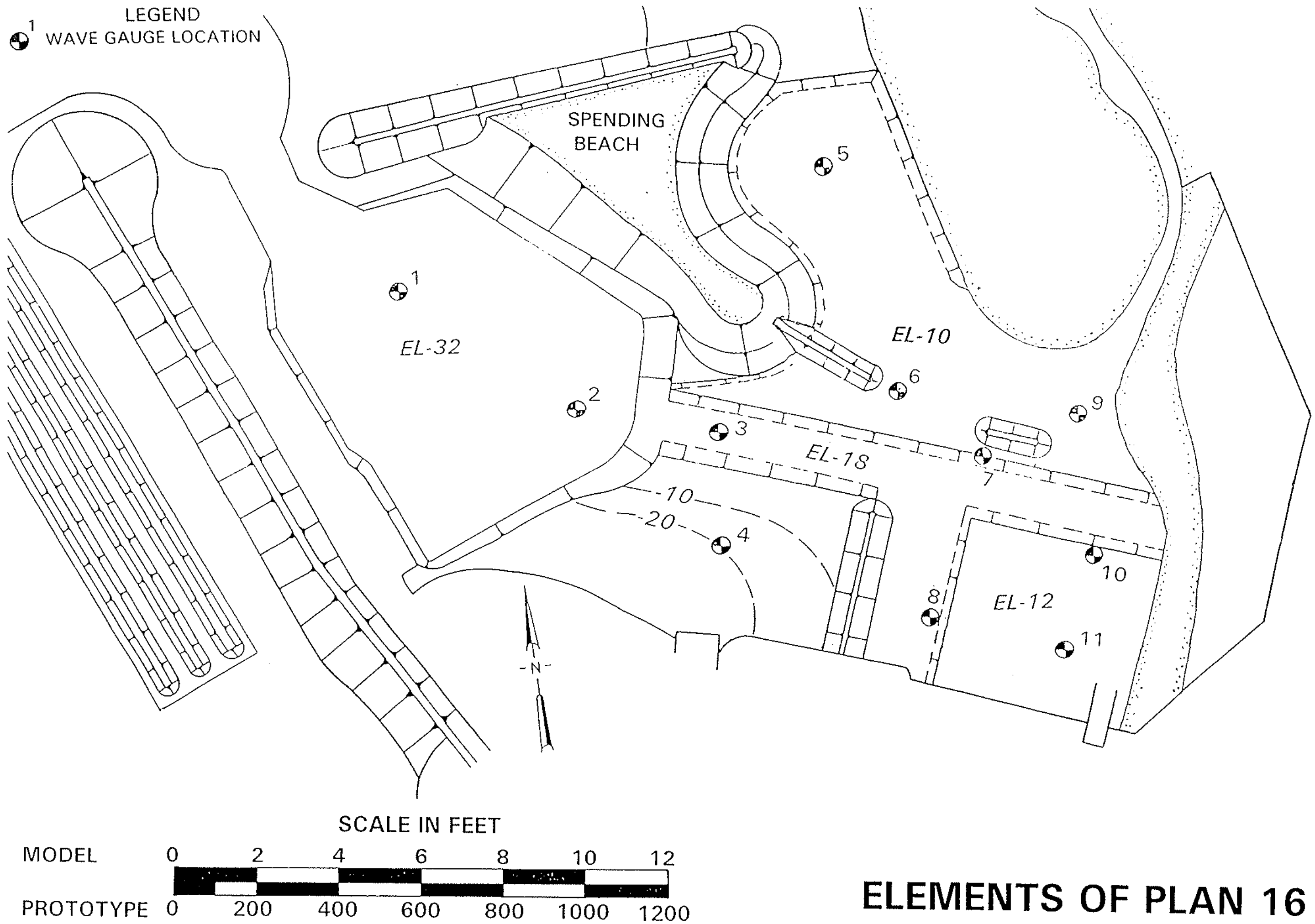
ELEMENTS OF PLAN 13



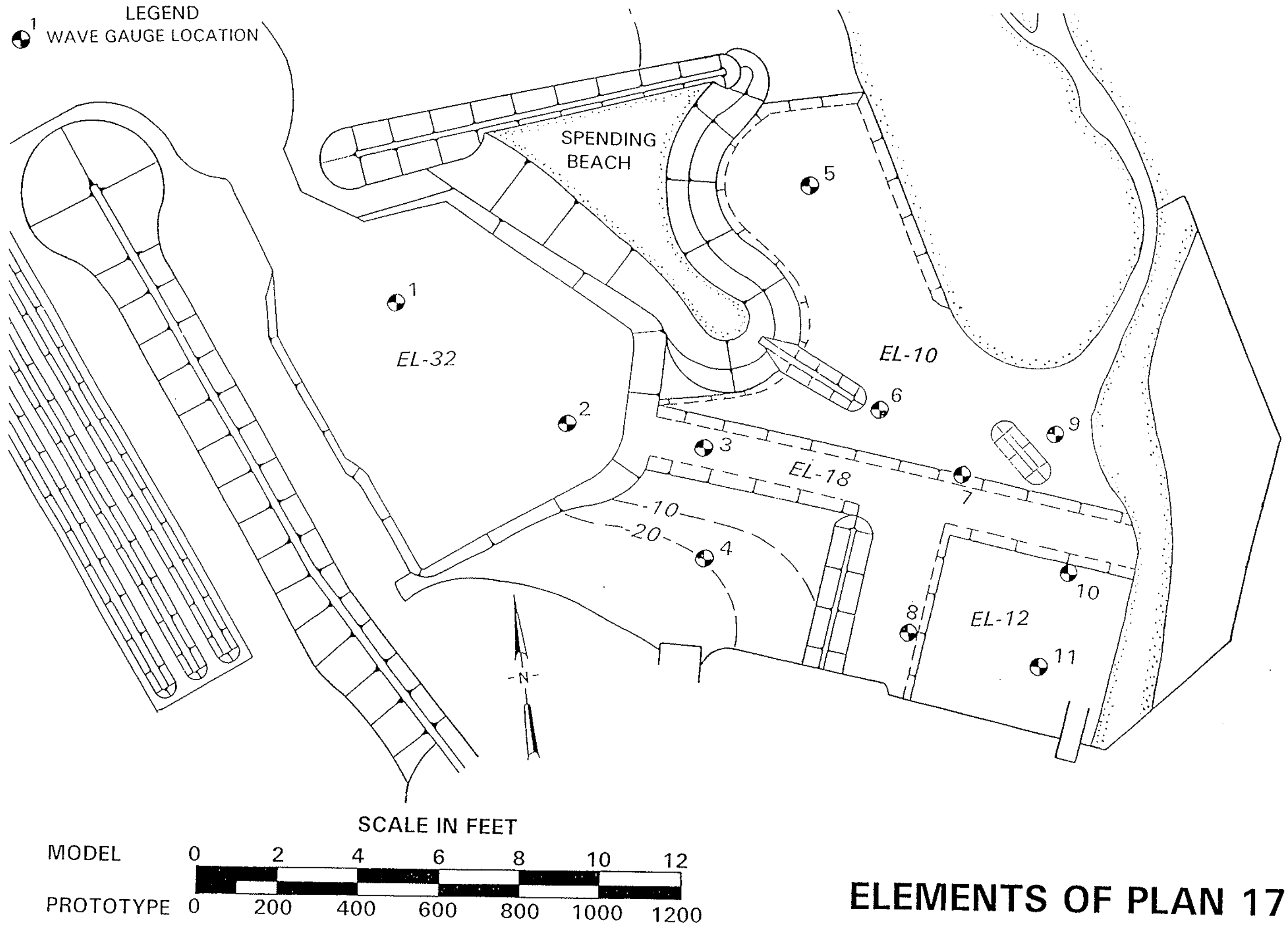
ELEMENTS OF PLAN 14



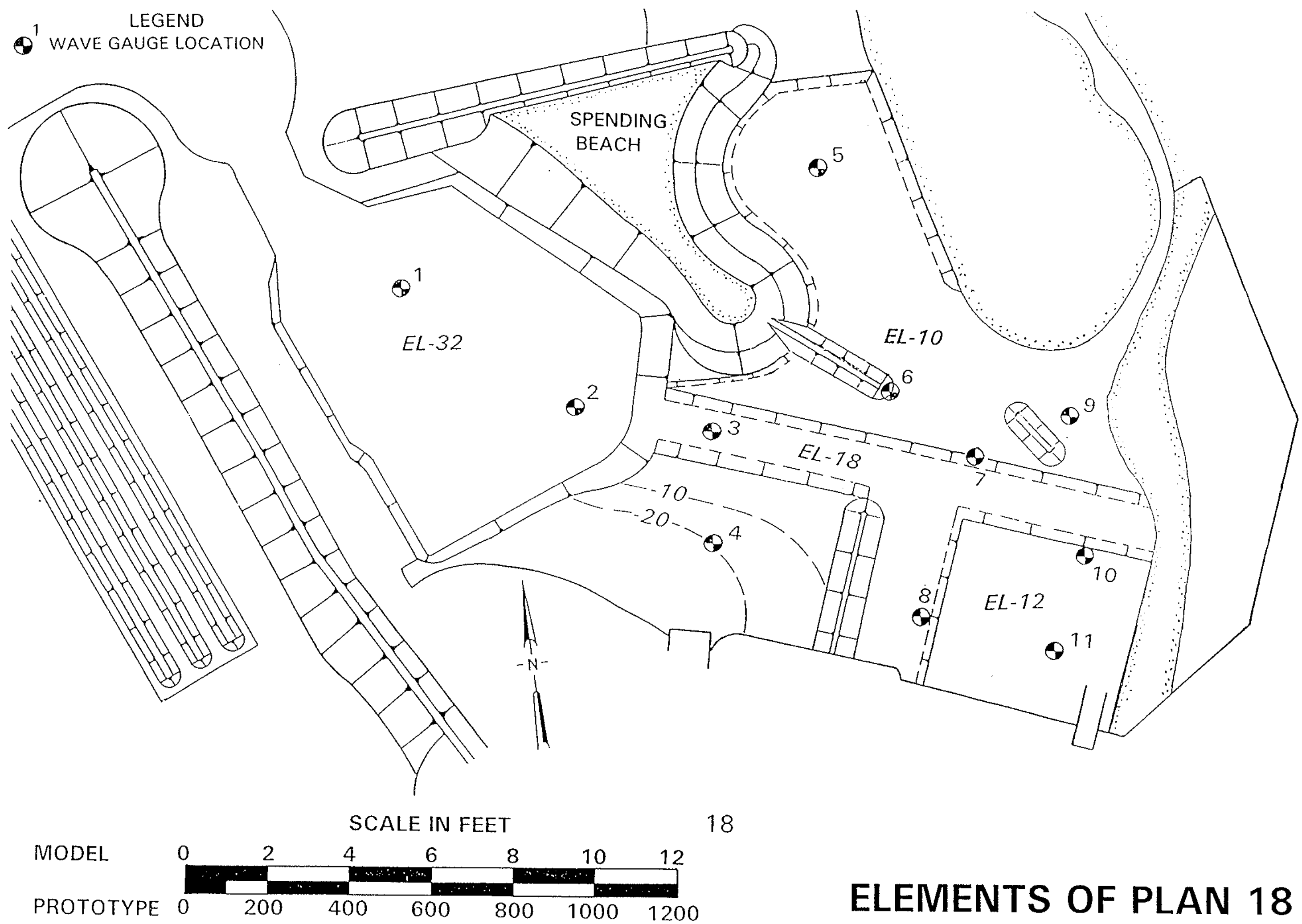
ELEMENTS OF PLAN 15



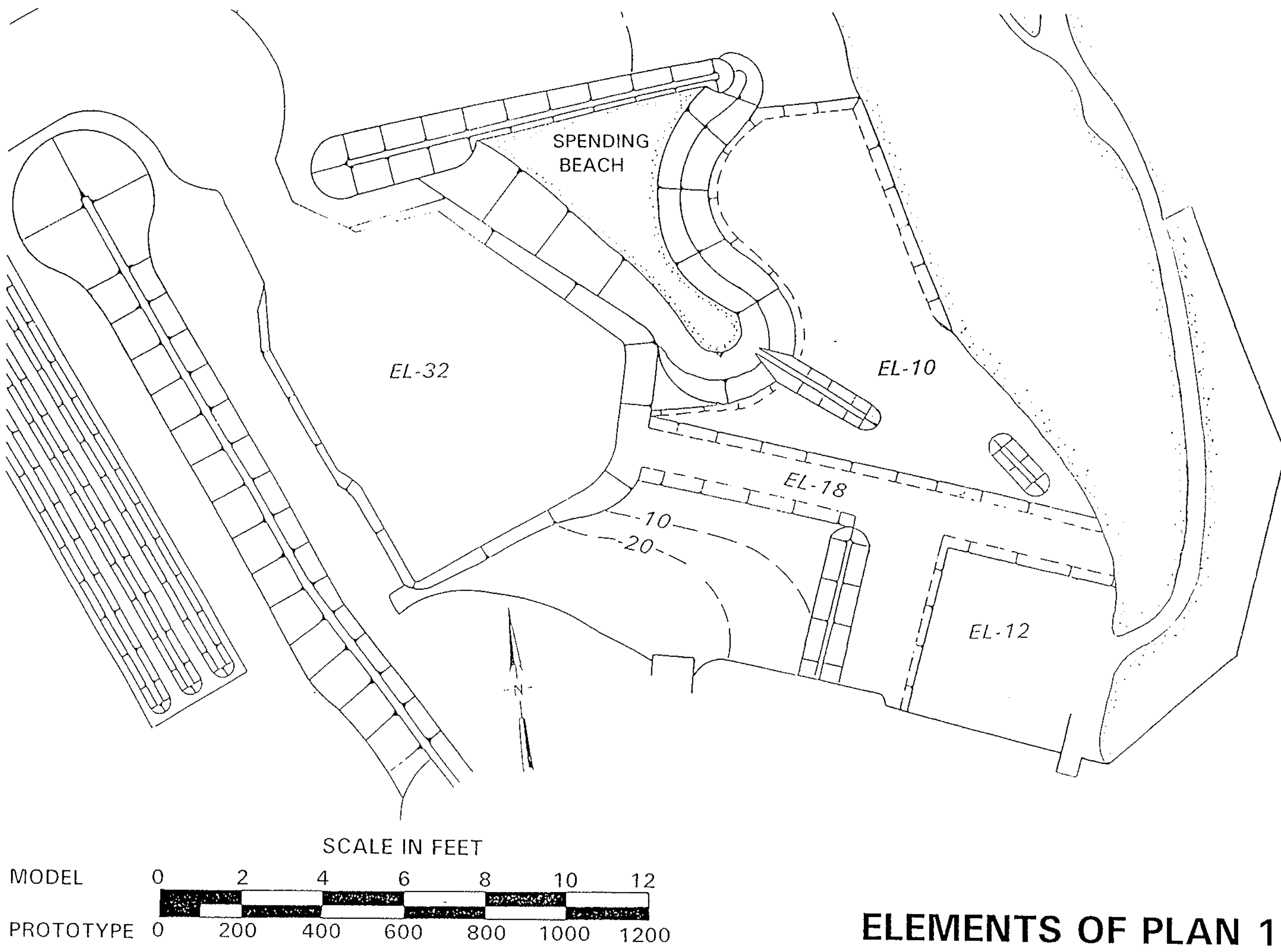
ELEMENTS OF PLAN 16



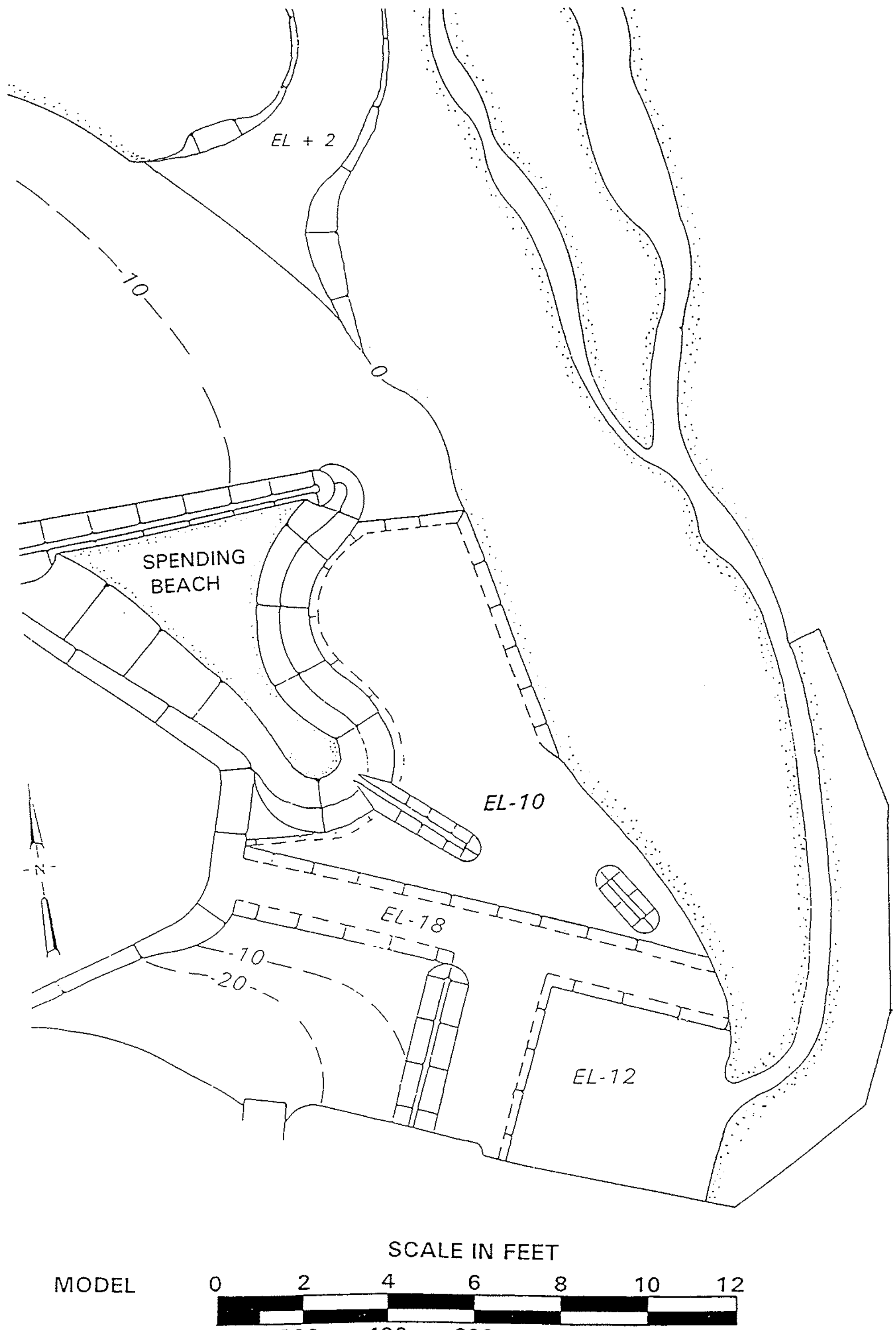
ELEMENTS OF PLAN 17



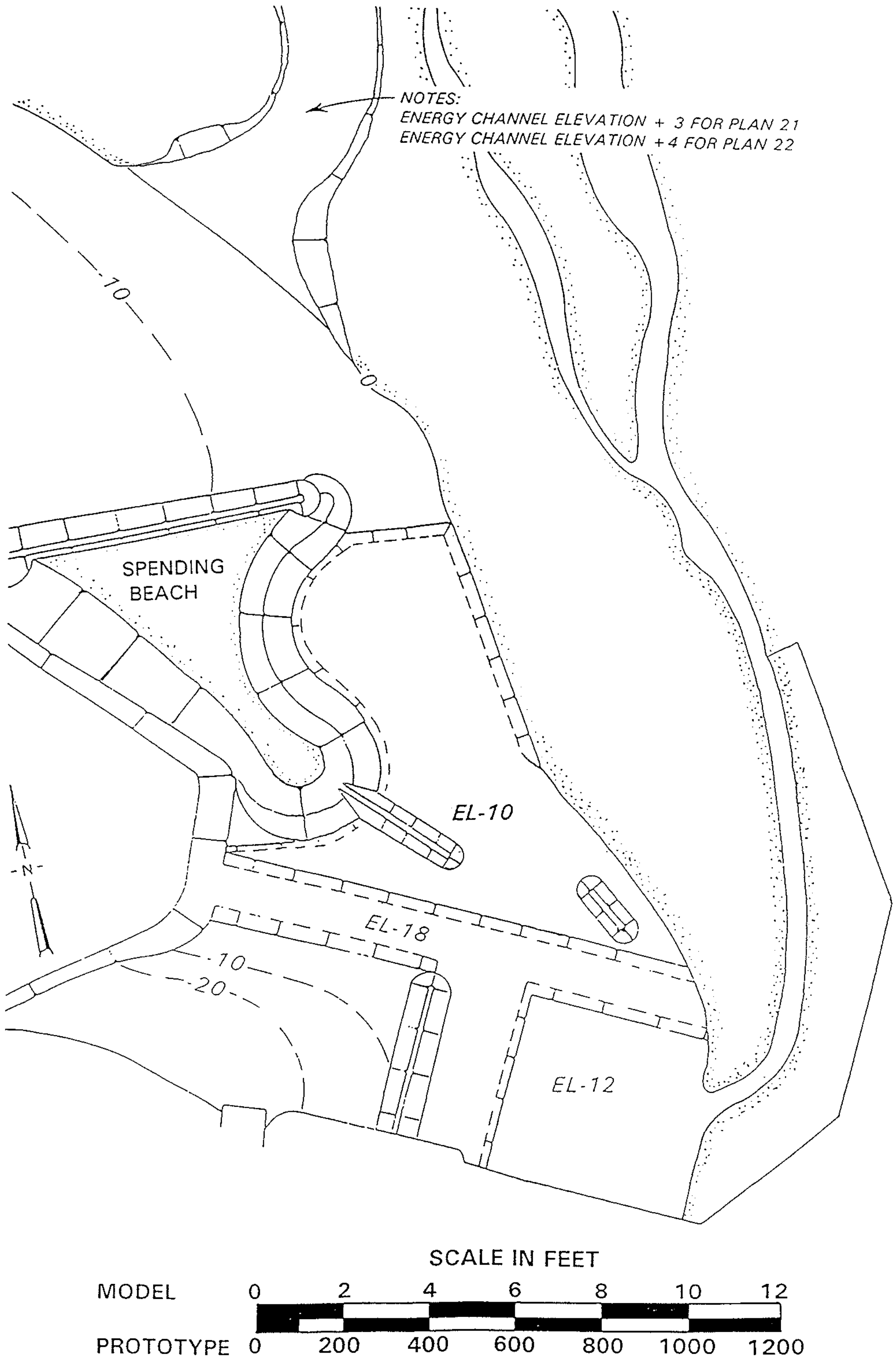
ELEMENTS OF PLAN 18



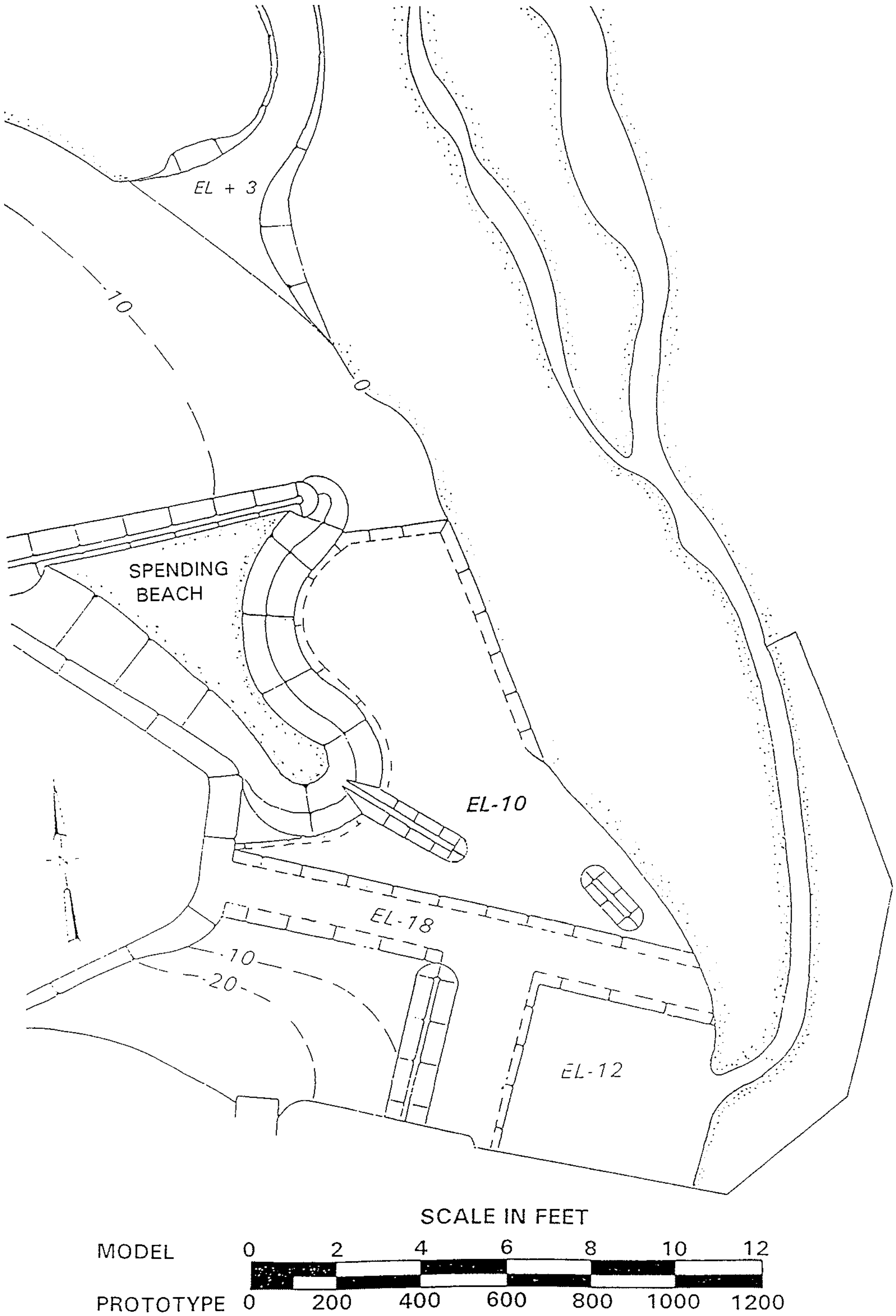
ELEMENTS OF PLAN 19



ELEMENTS OF PLAN 20

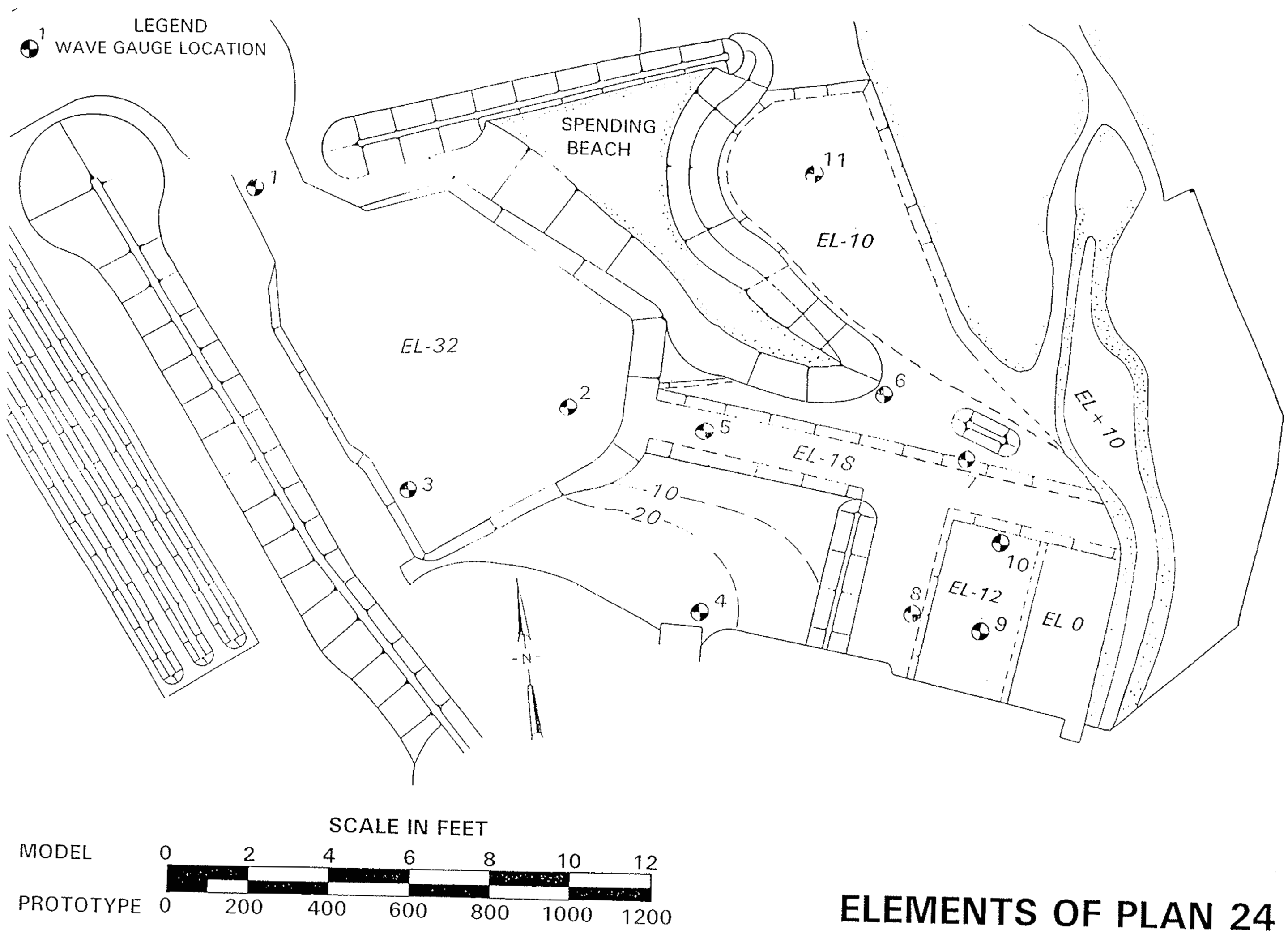


ELEMENTS OF PLANS 21-22



ELEMENTS OF PLAN 23

Plate 10



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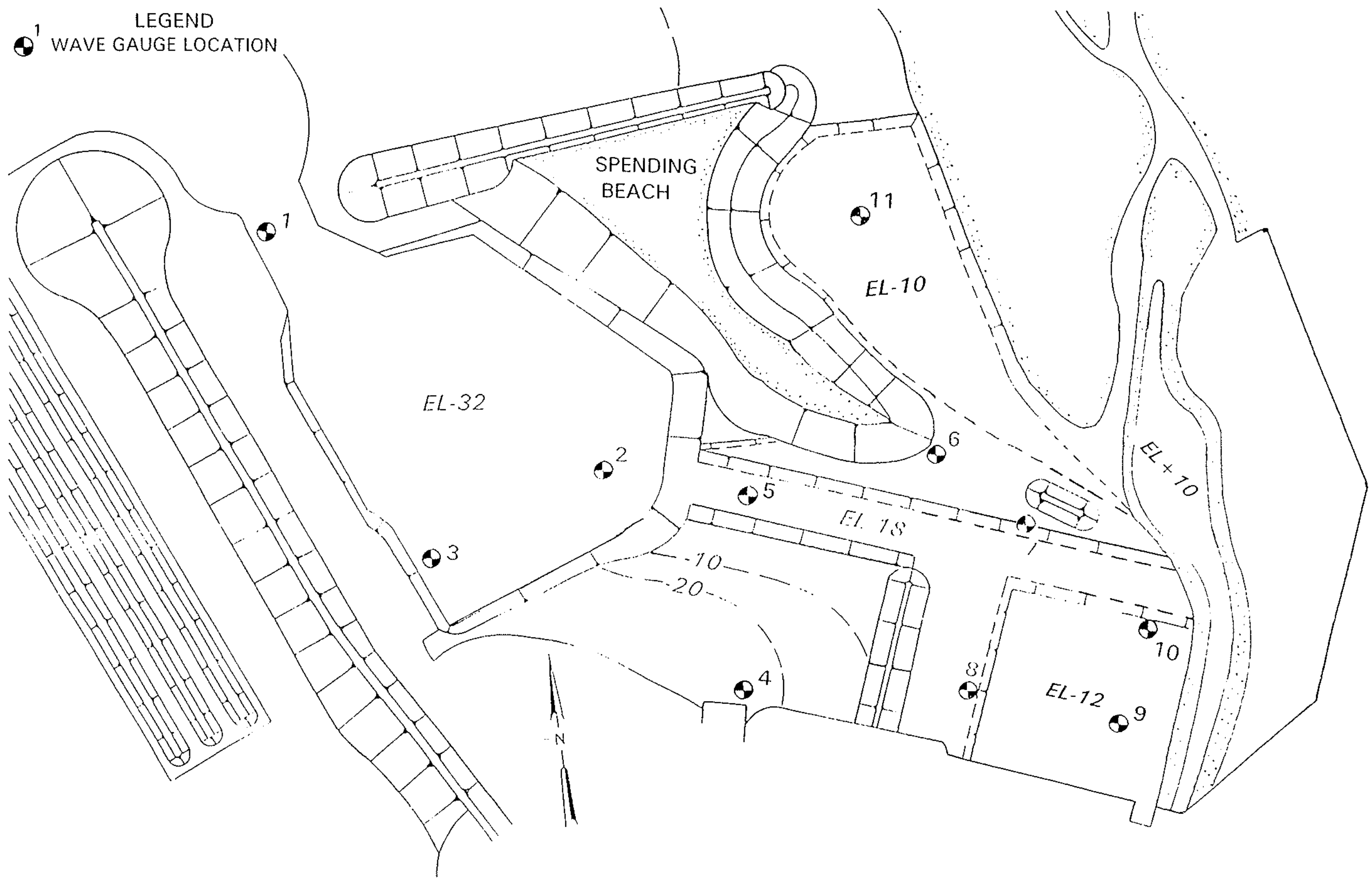

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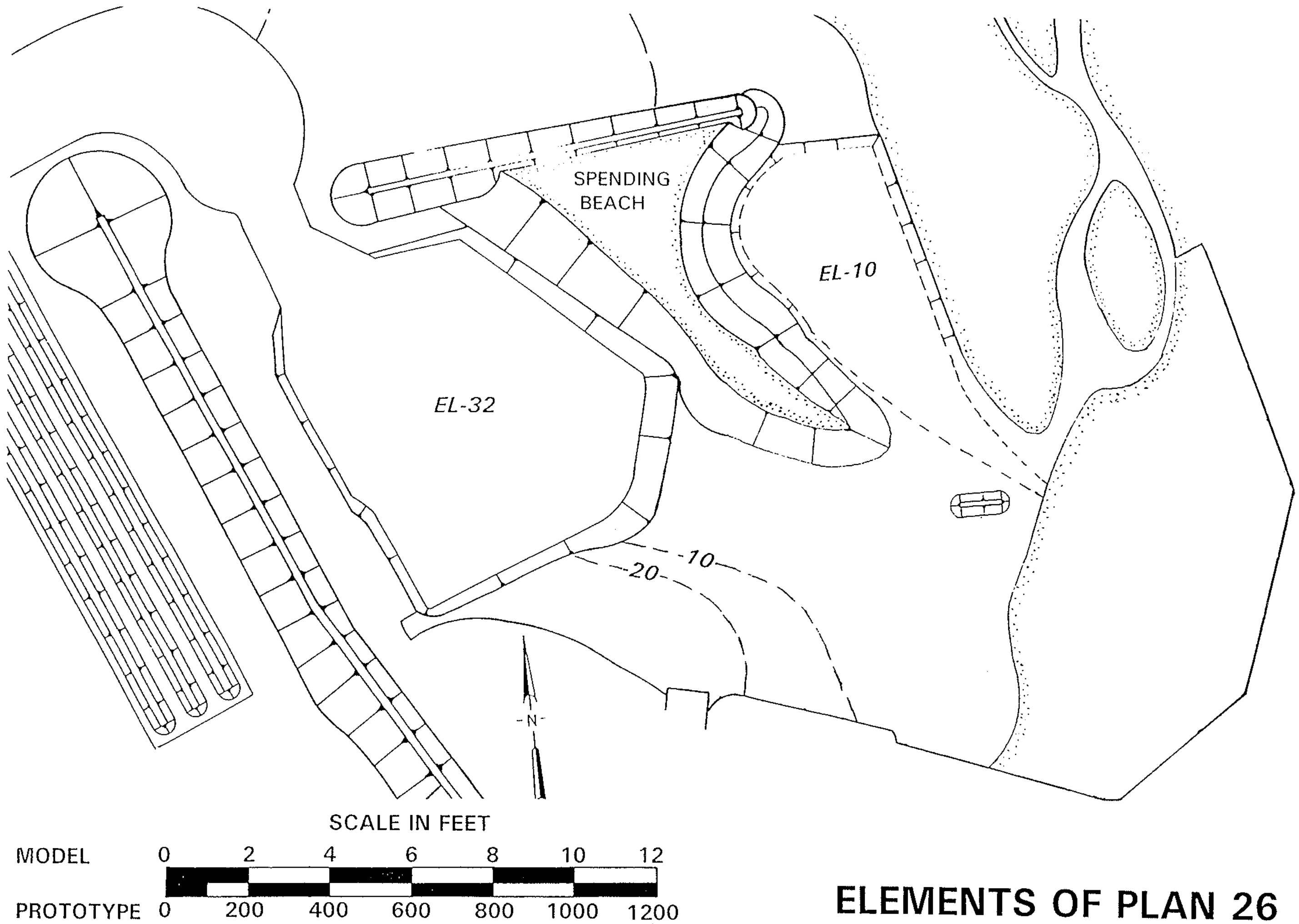
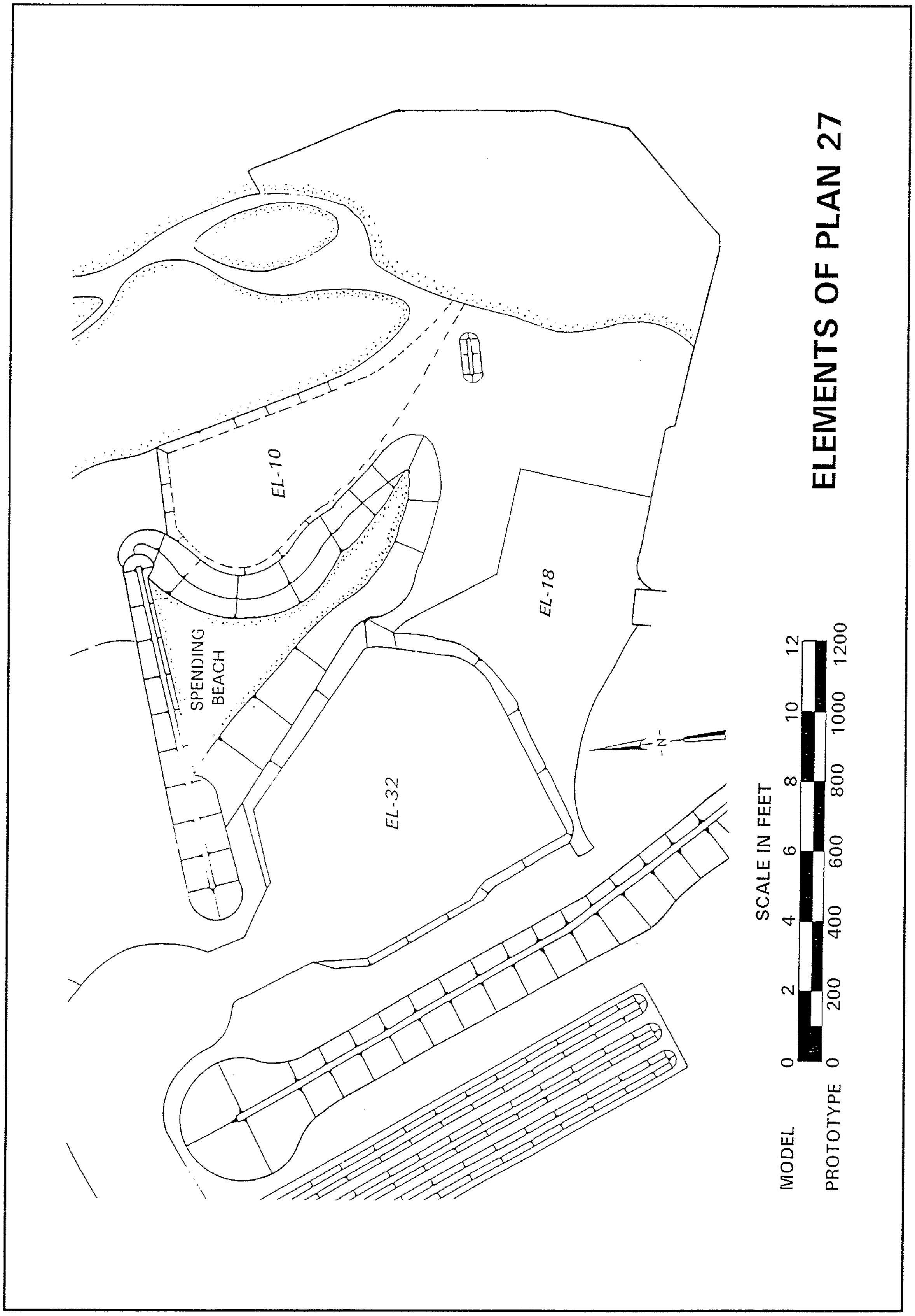


ELEMENTS OF PLAN 26



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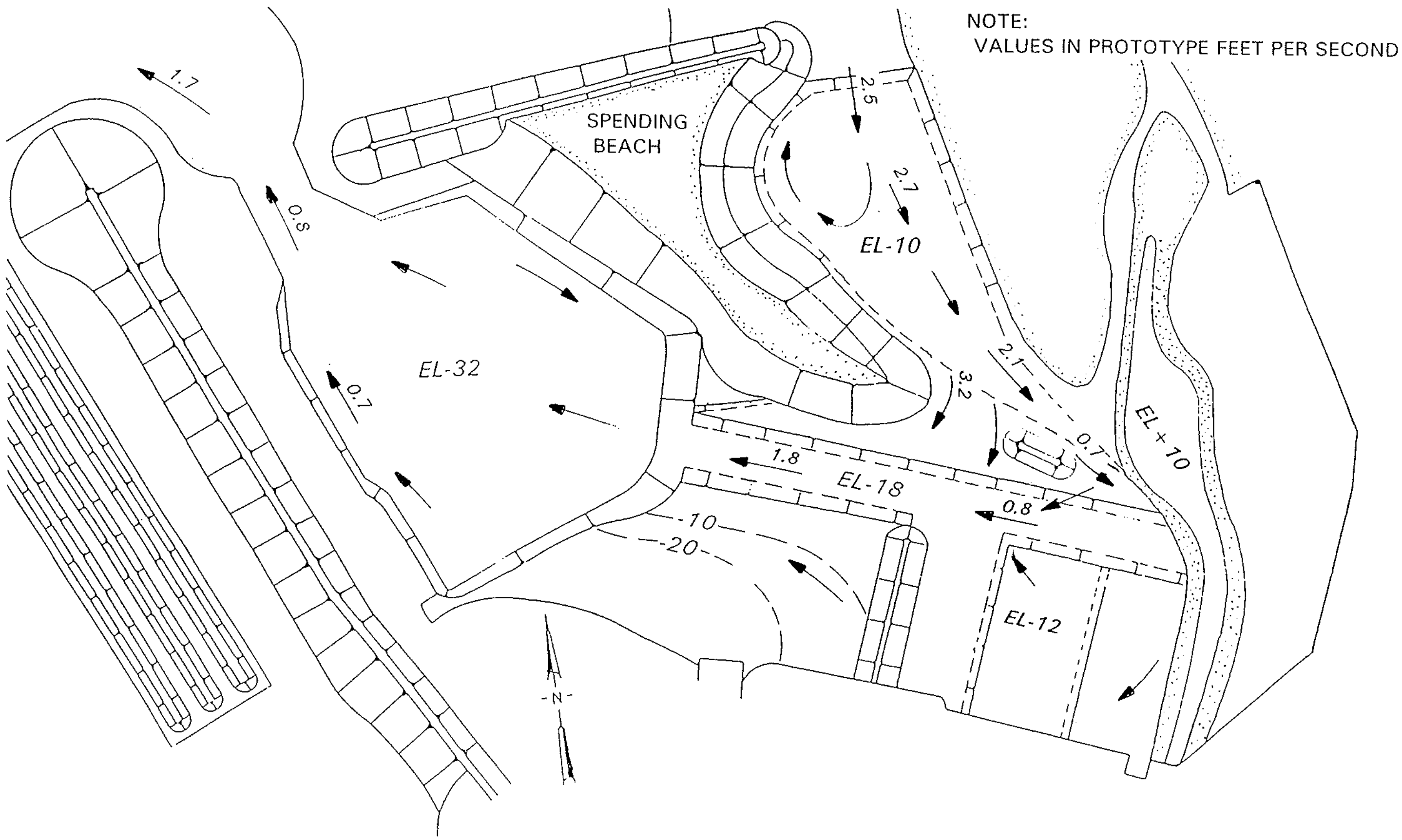
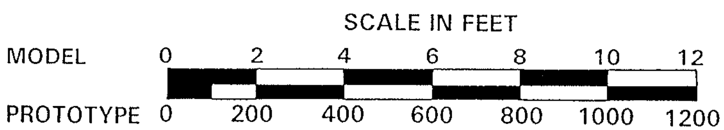
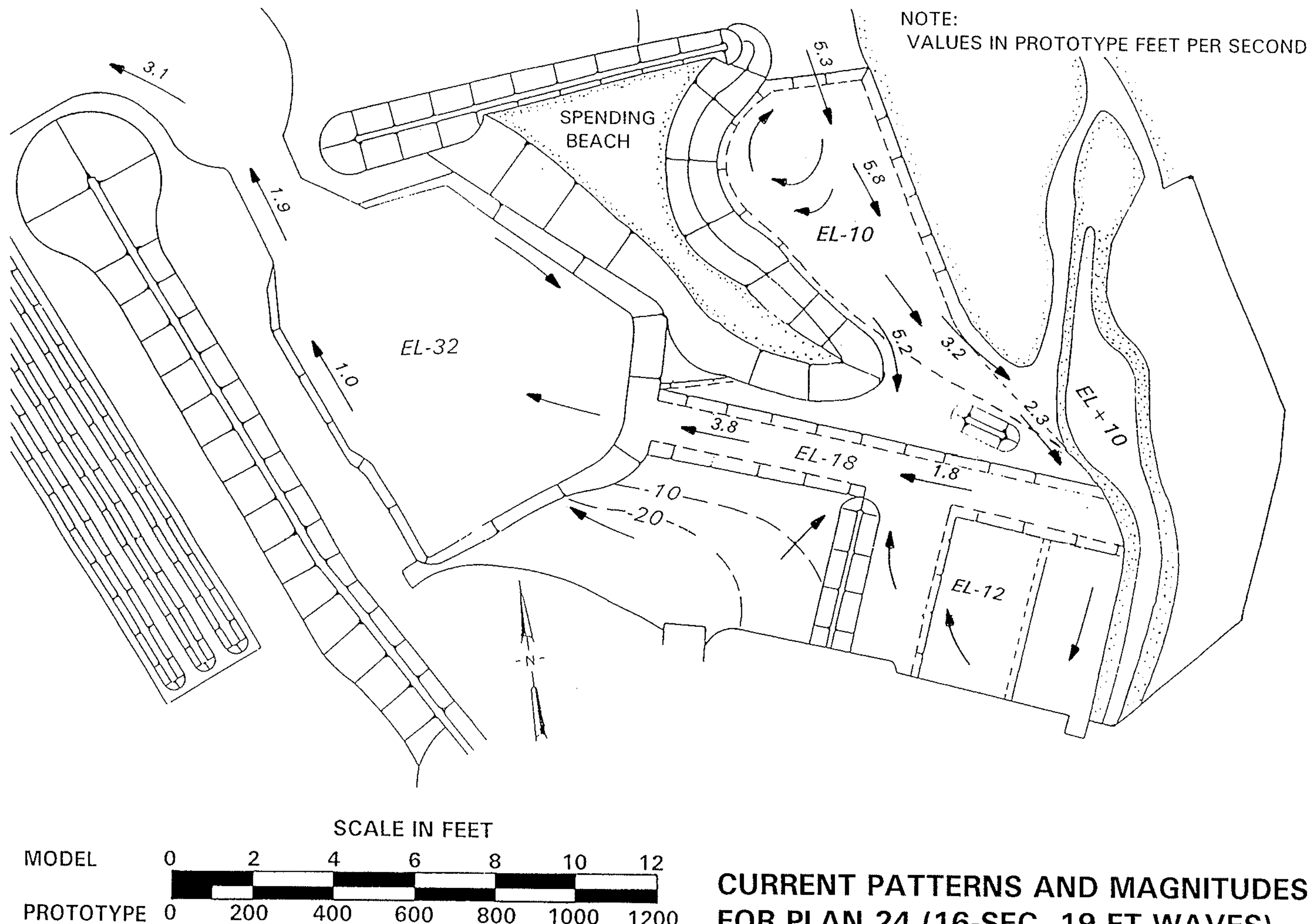
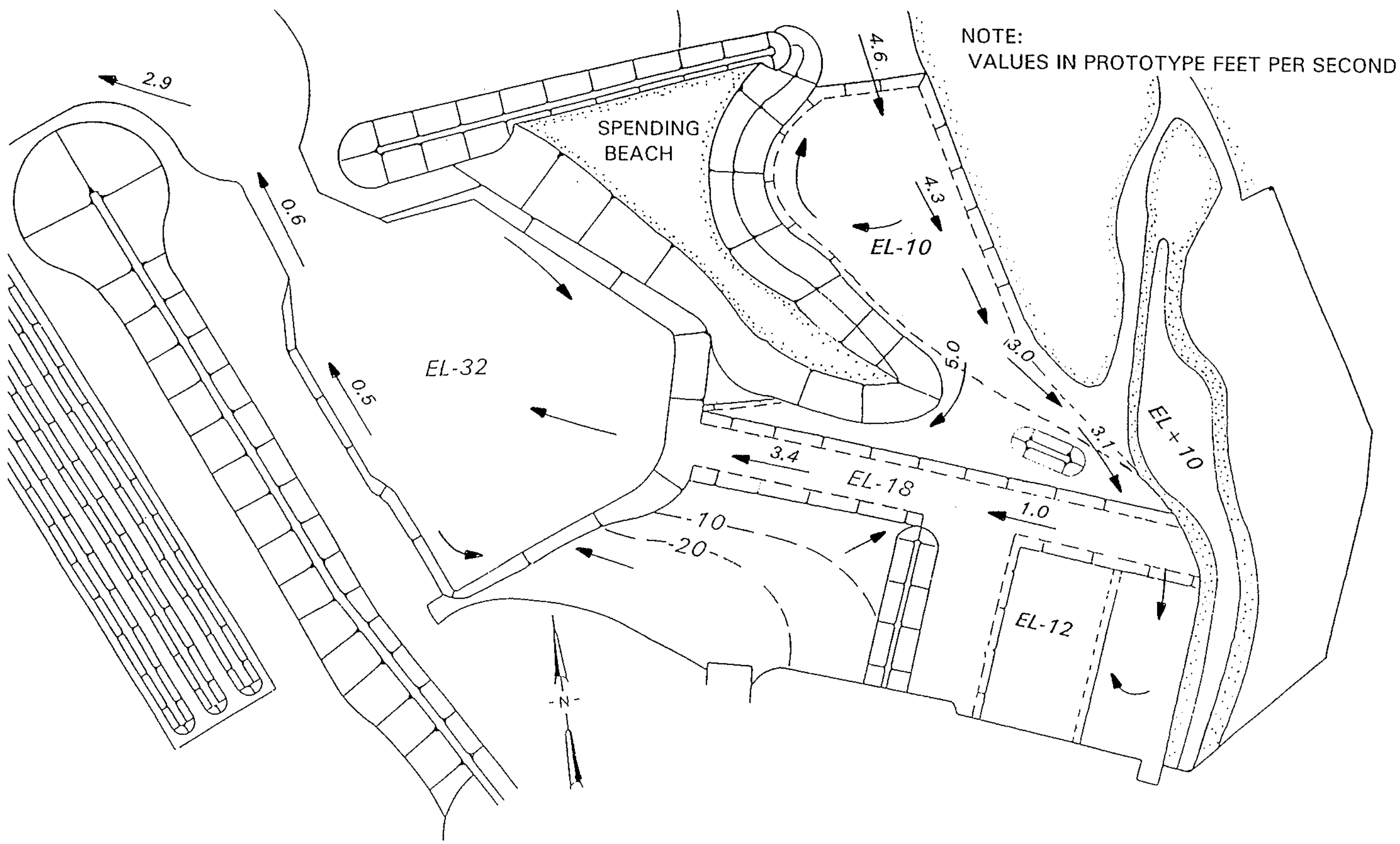




CURRENT PATTERNS AND MAGNITUDES FOR PLAN 24 (8-SEC, 10-FT WAVES)



CURRENT PATTERNS AND MAGNITUDES FOR PLAN 24 (16-SEC, 19-FT WAVES)



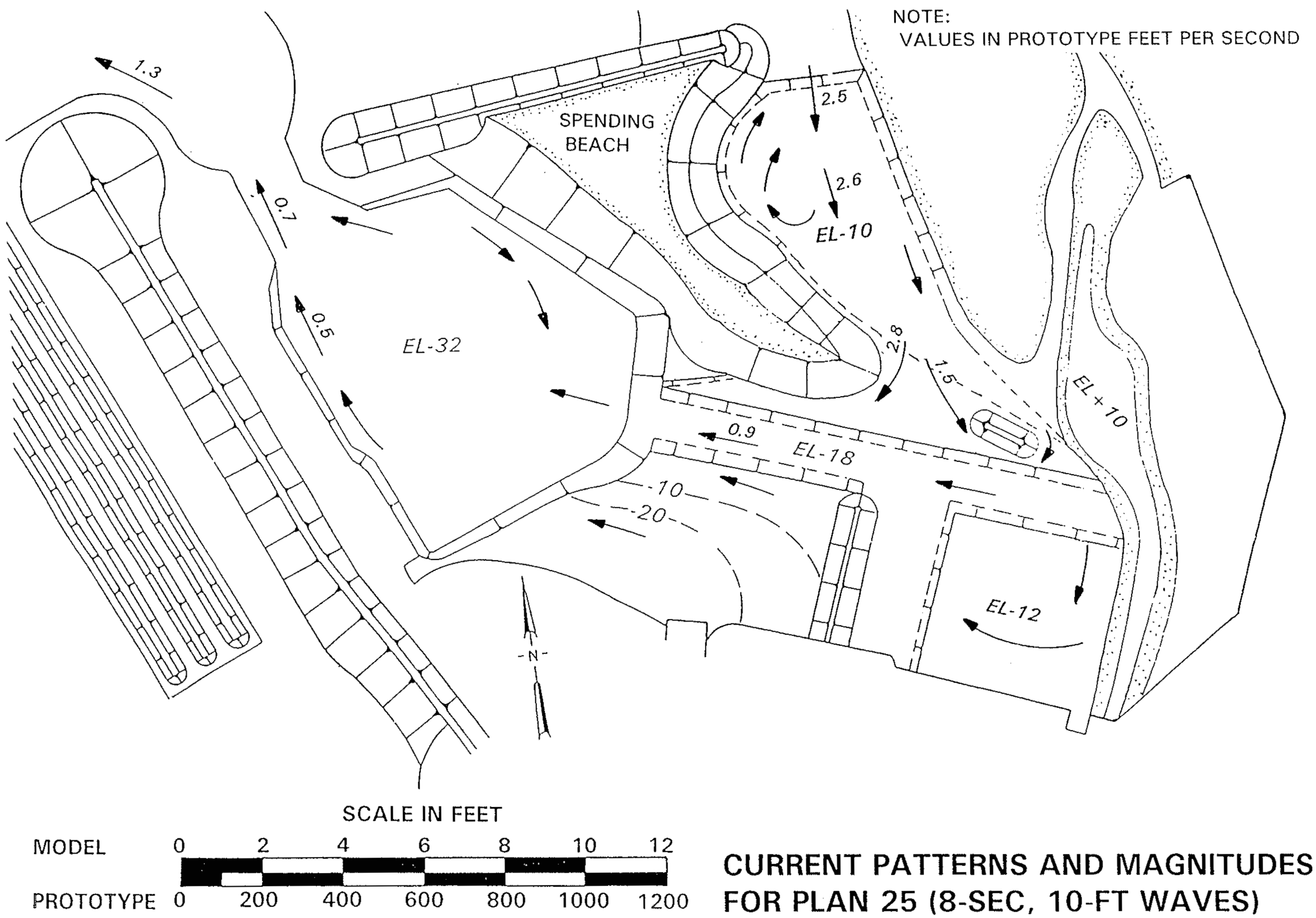
SCALE IN FEET

MODEL 0 2 4 6 8 10 12

PROTOTYPE 0 200 400 600 800 1000 1200

CURRENT PATTERNS AND MAGNITUDES FOR PLAN 24 (20-SEC, 14-FT WAVES)

Plate 18



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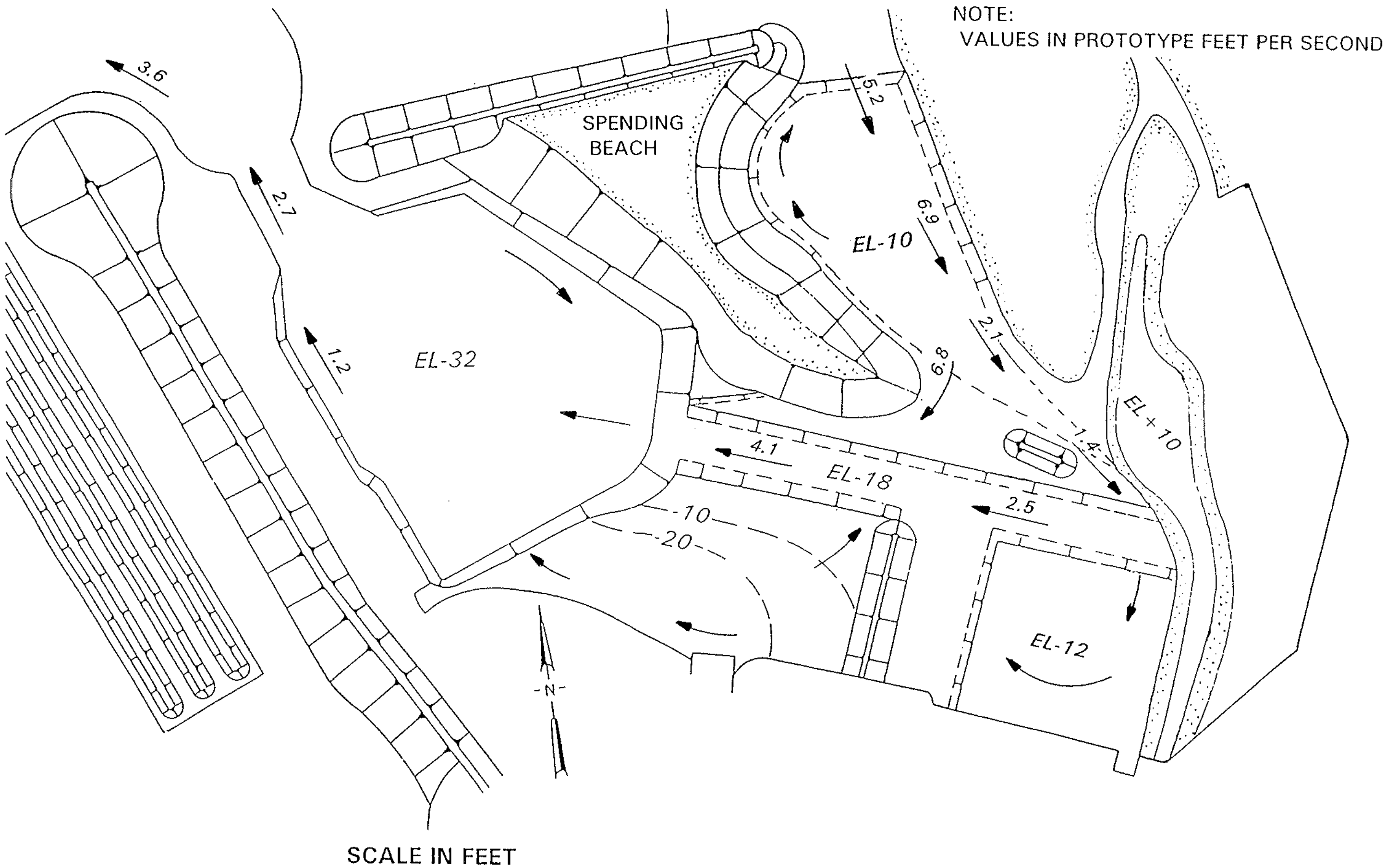

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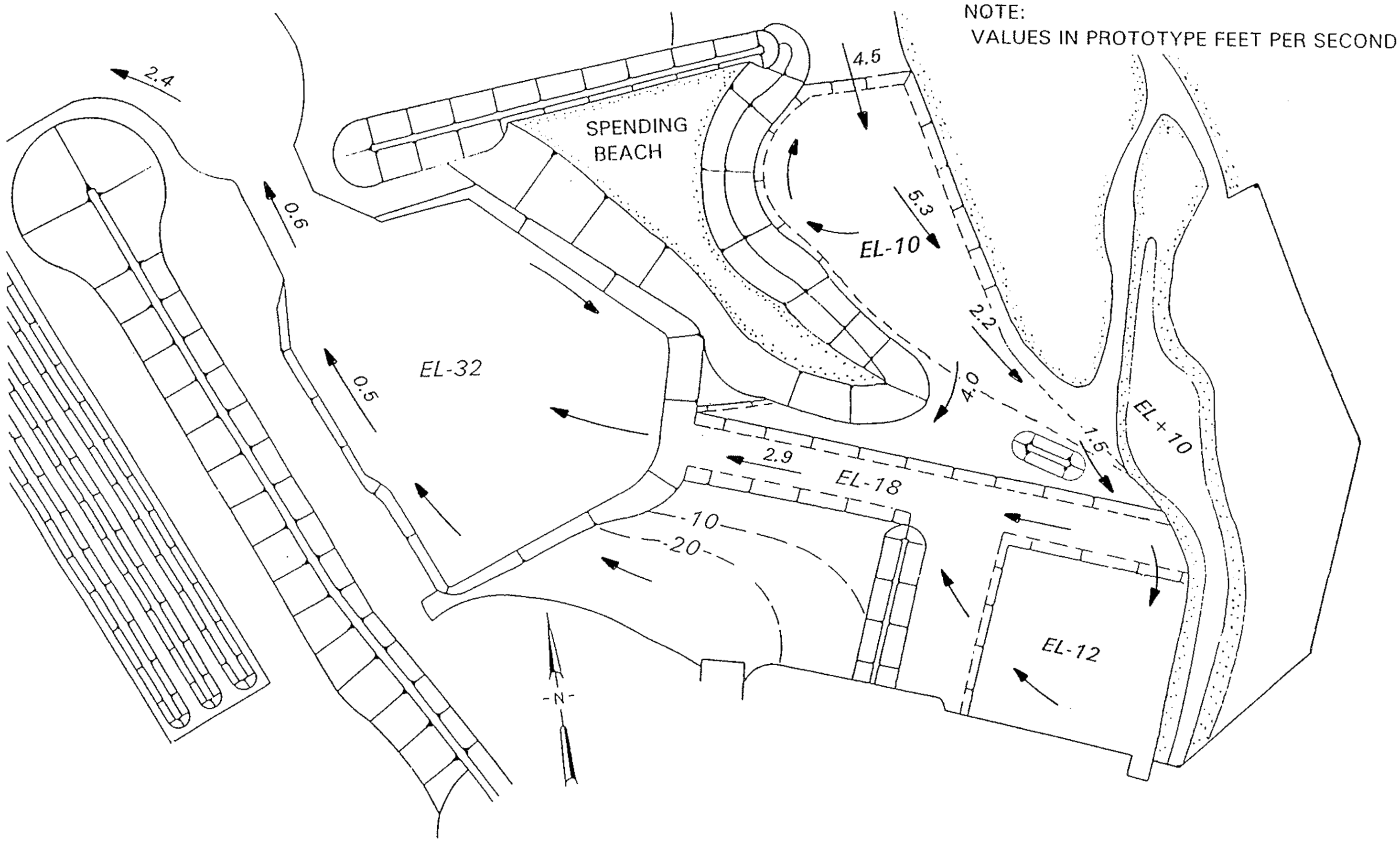

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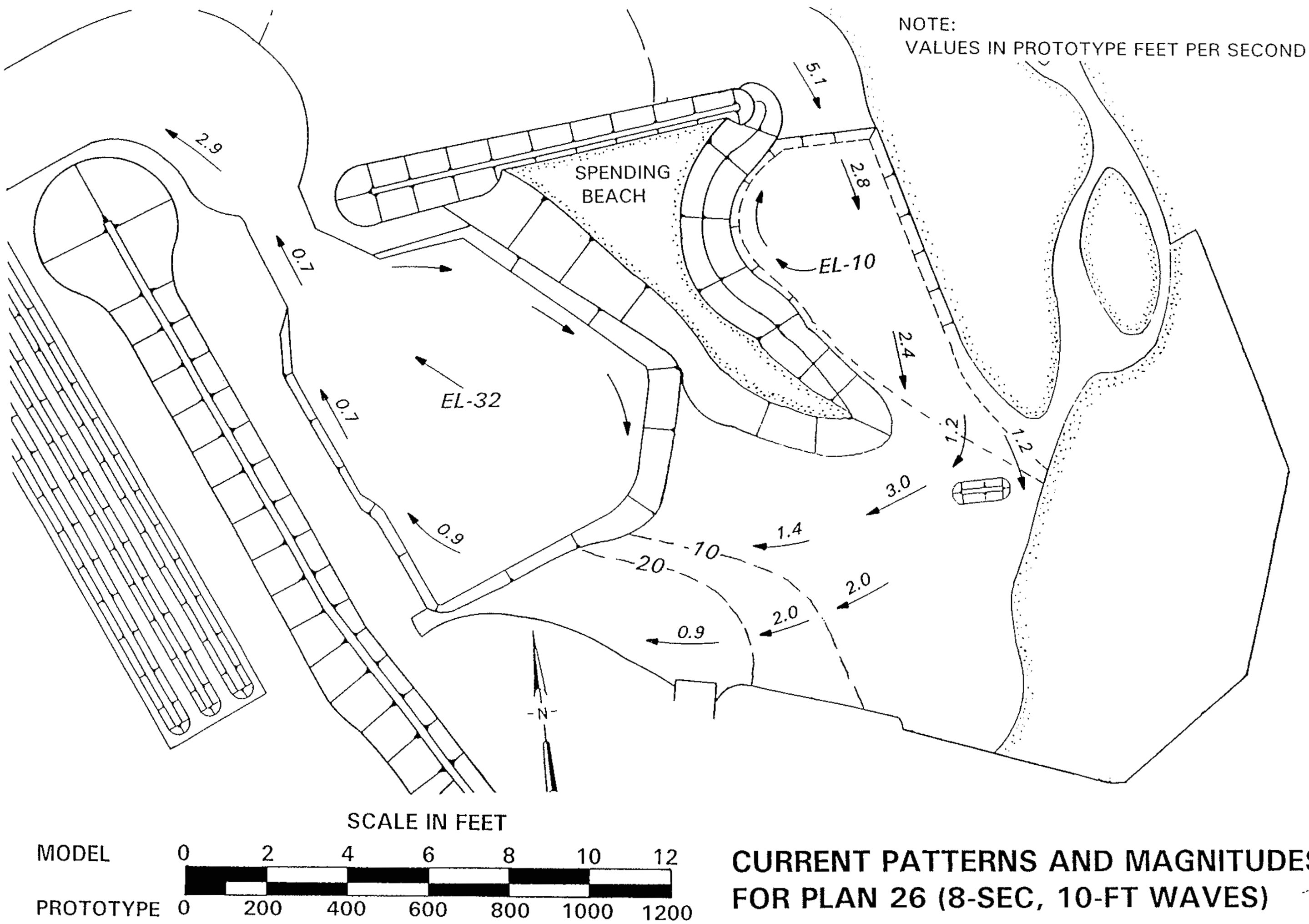

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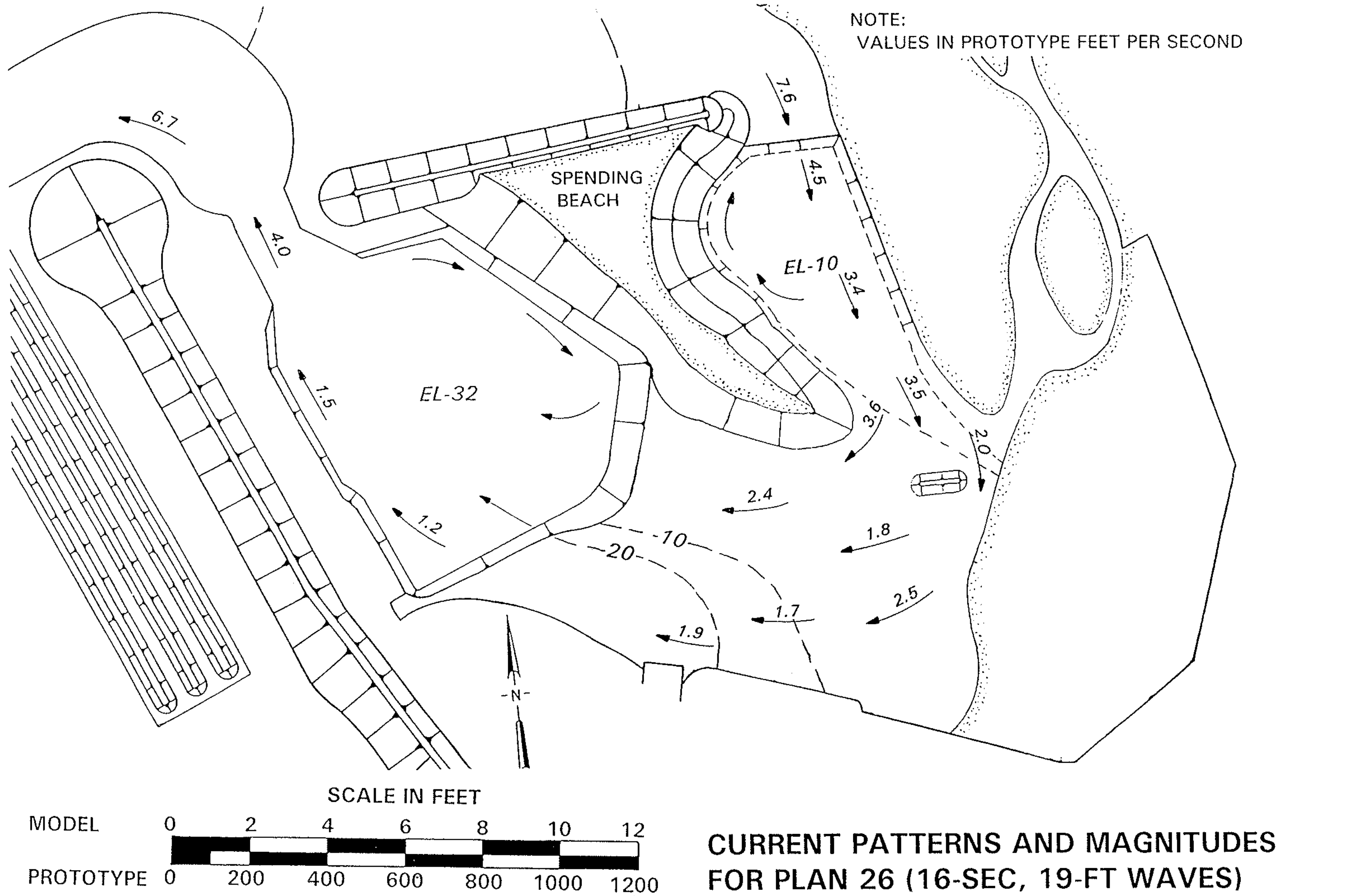
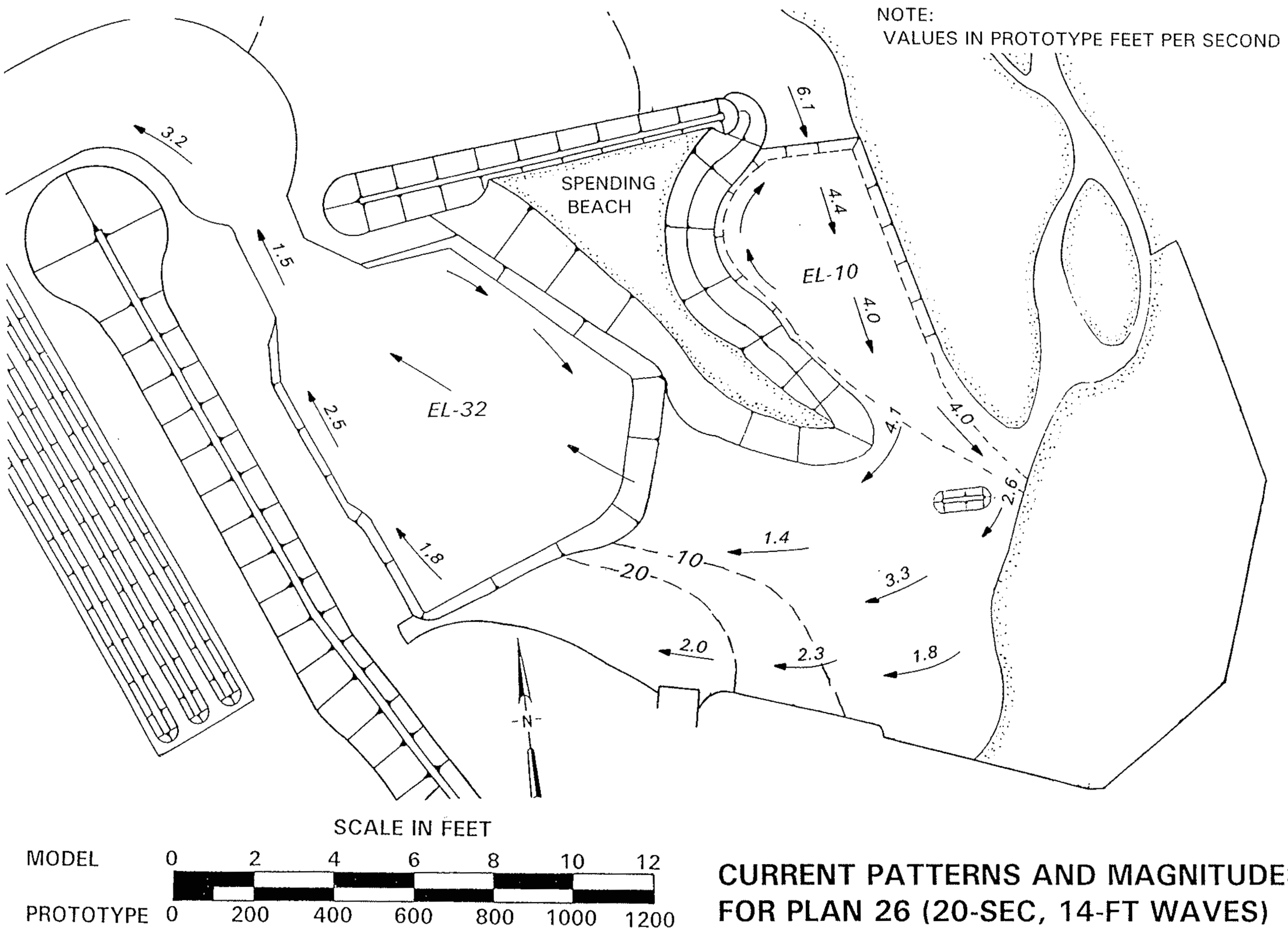
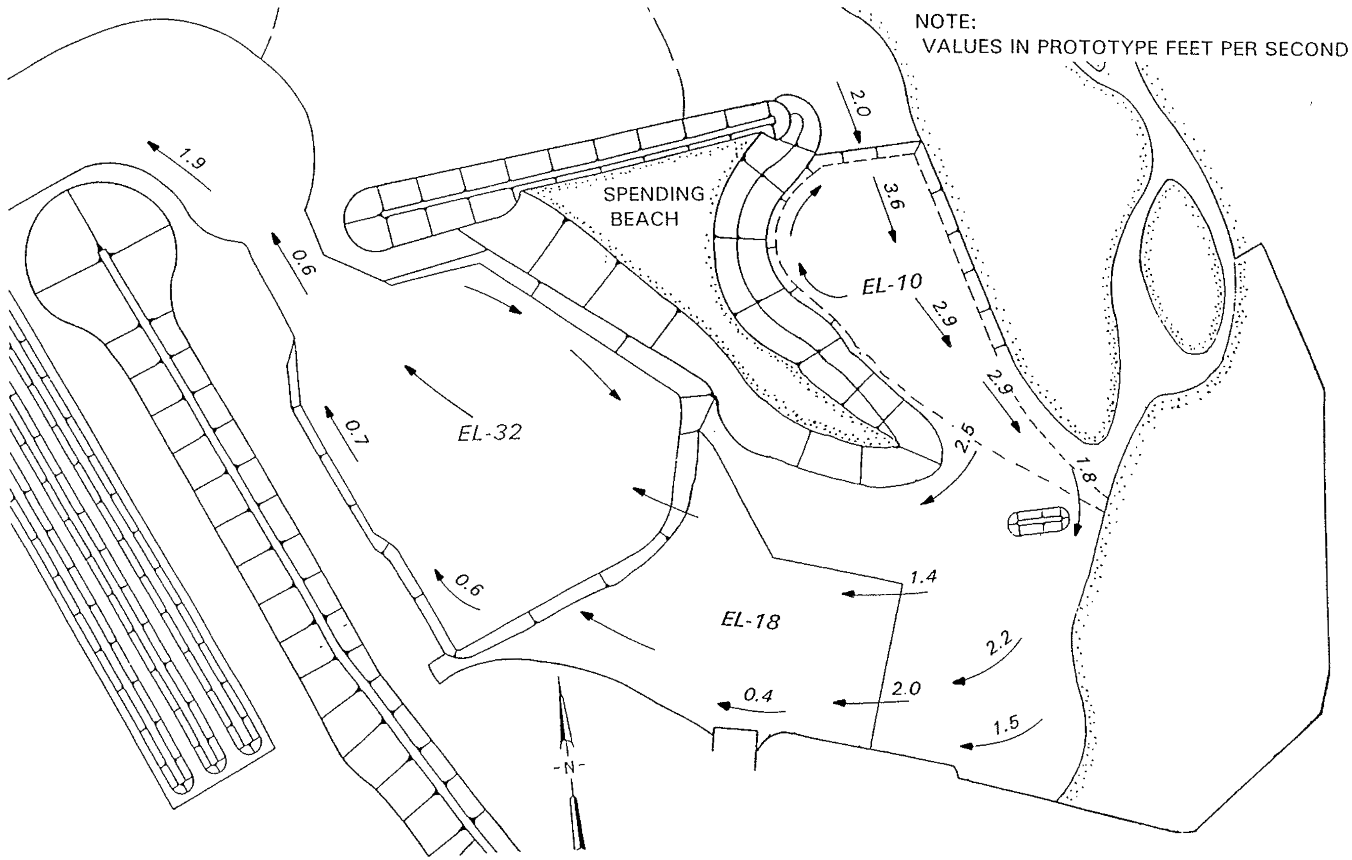
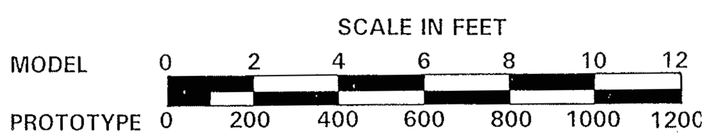


CURRENT PATTERNS AND MAGNITUDES FOR PLAN 26 (16-SEC, 19-FT WAVES)

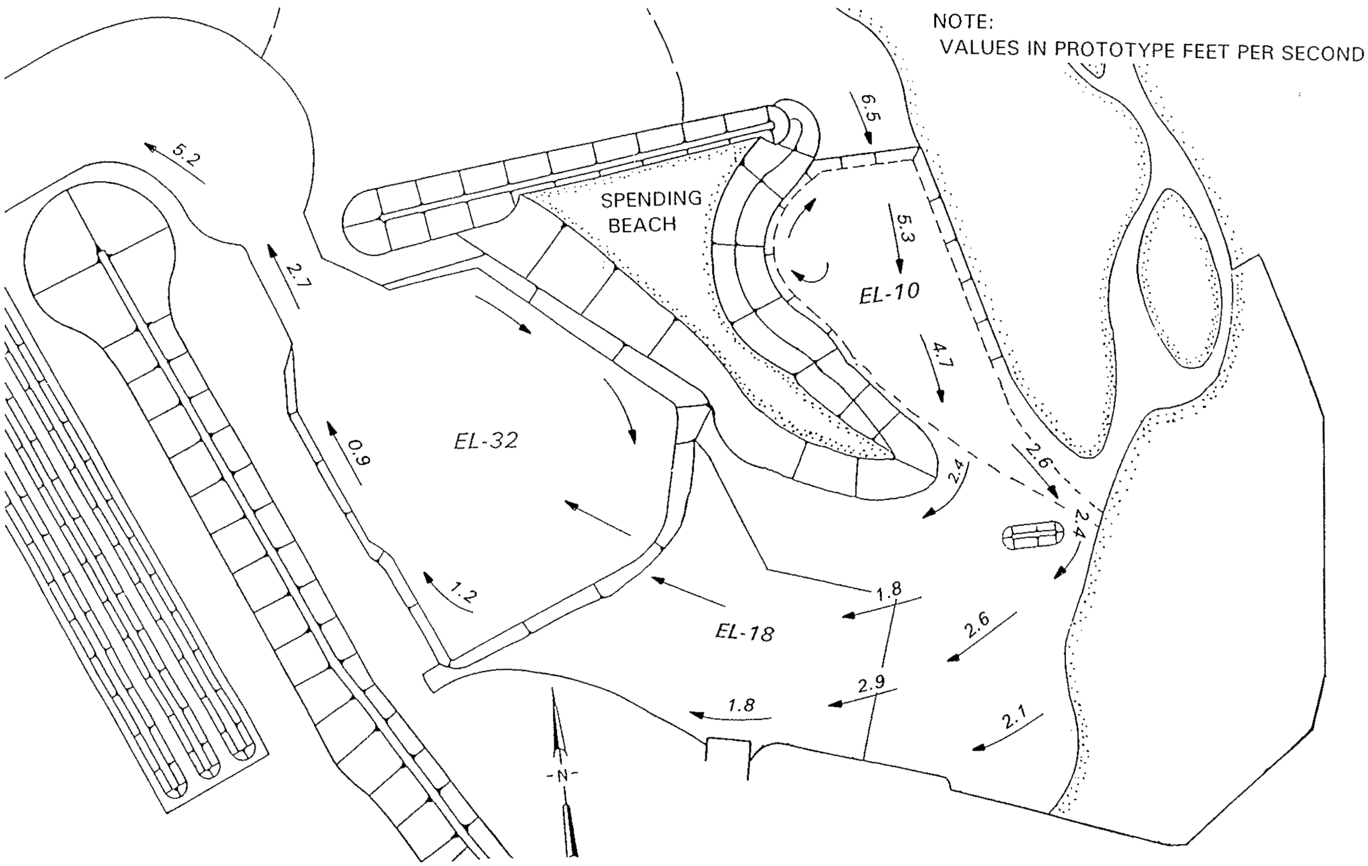


CURRENT PATTERNS AND MAGNITUDES FOR PLAN 26 (20-SEC, 14-FT WAVES)





CURRENT PATTERNS AND MAGNITUDES FOR PLAN 27 (8-SEC, 10-FT WAVES)

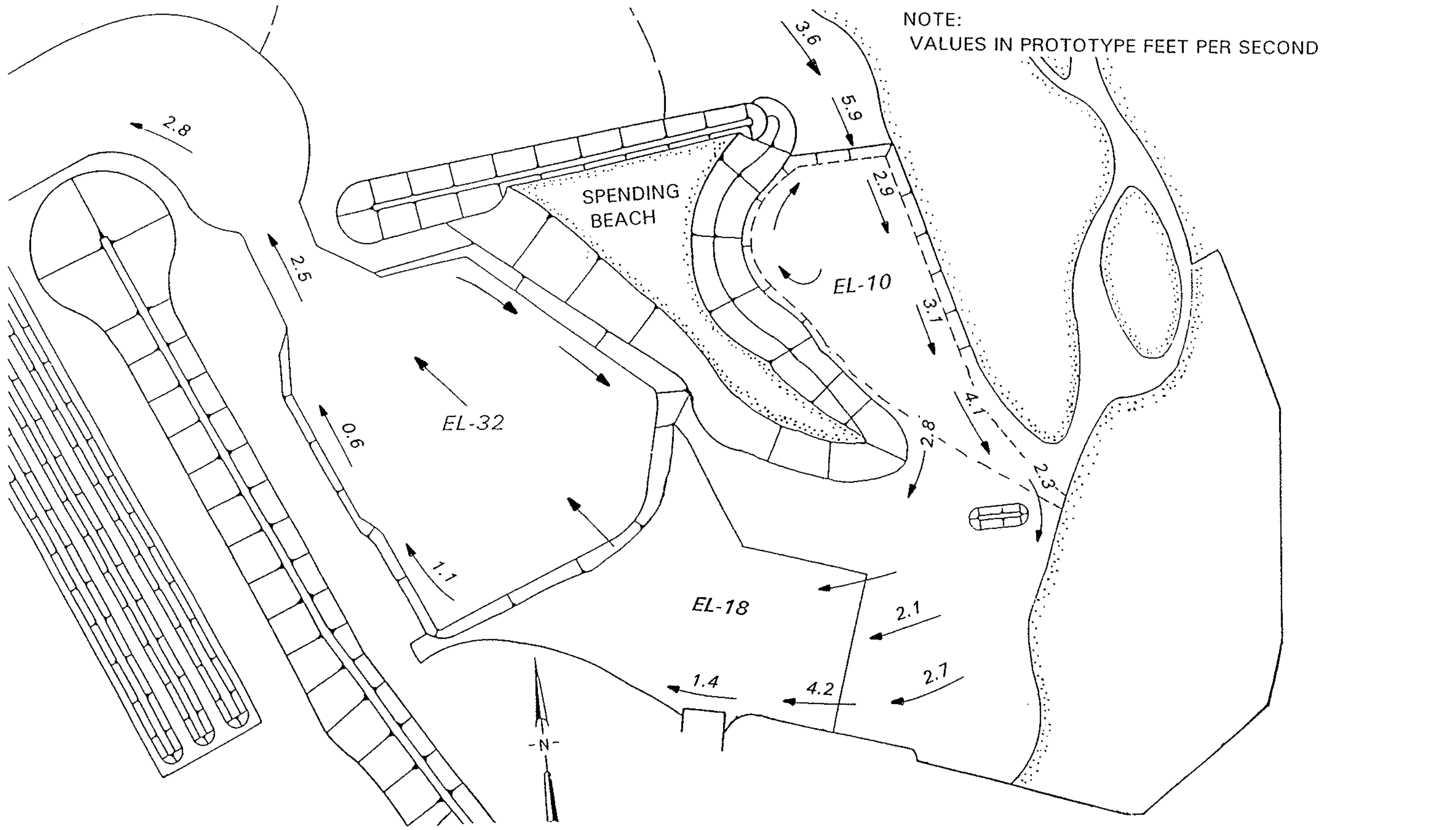


SCALE IN FEET

MODEL 0 2 4 6 8 10 12

PROTOTYPE 0 200 400 600 800 1000 1200

CURRENT PATTERNS AND MAGNITUDES FOR PLAN 27 (16-SEC, 19-FT WAVES)

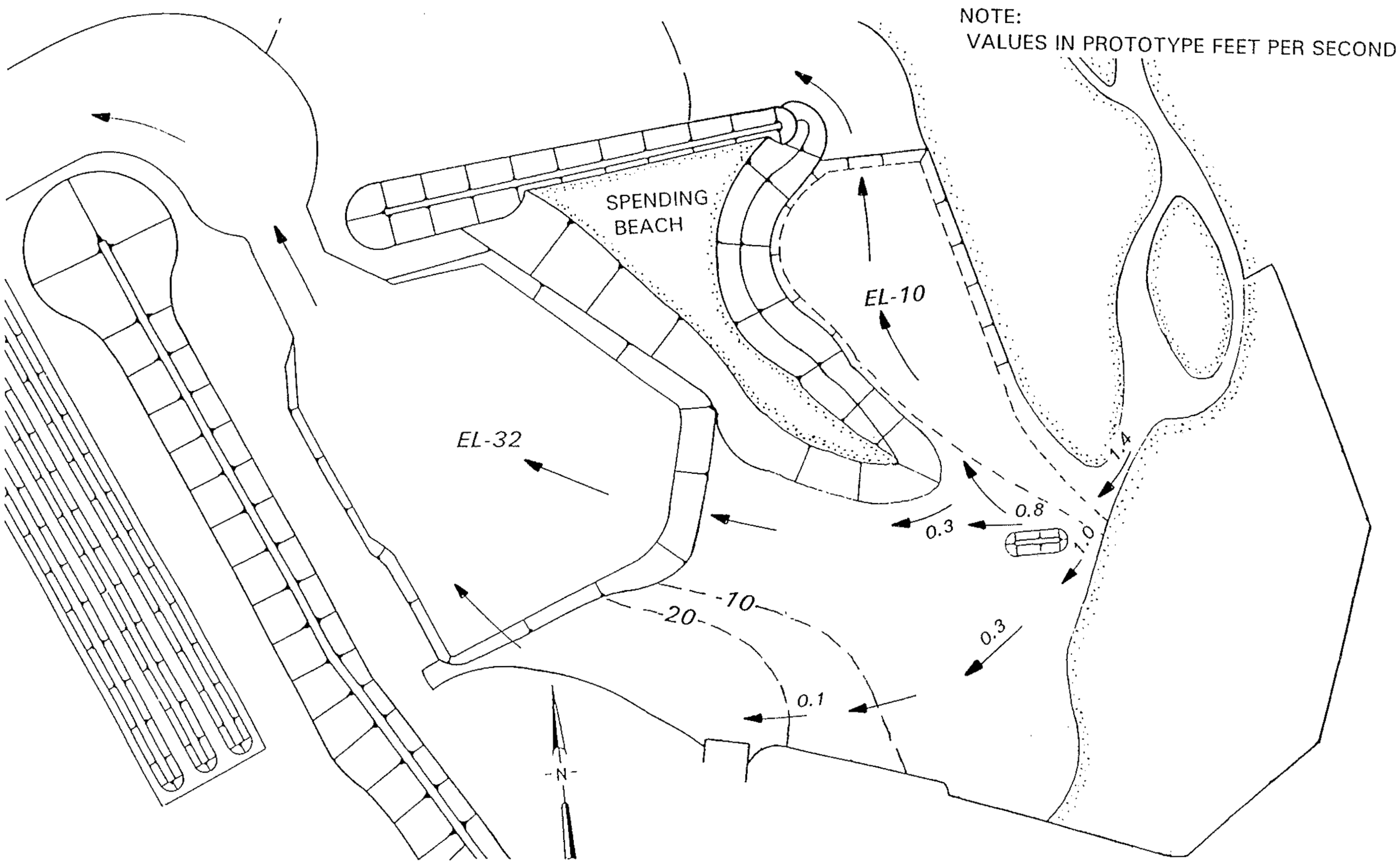


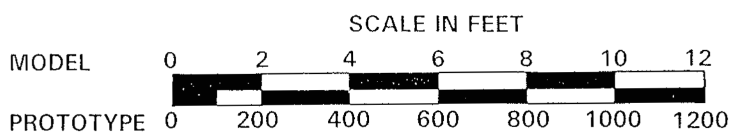
SCALE IN FEET

MODEL 0 2 4 6 8 10 12

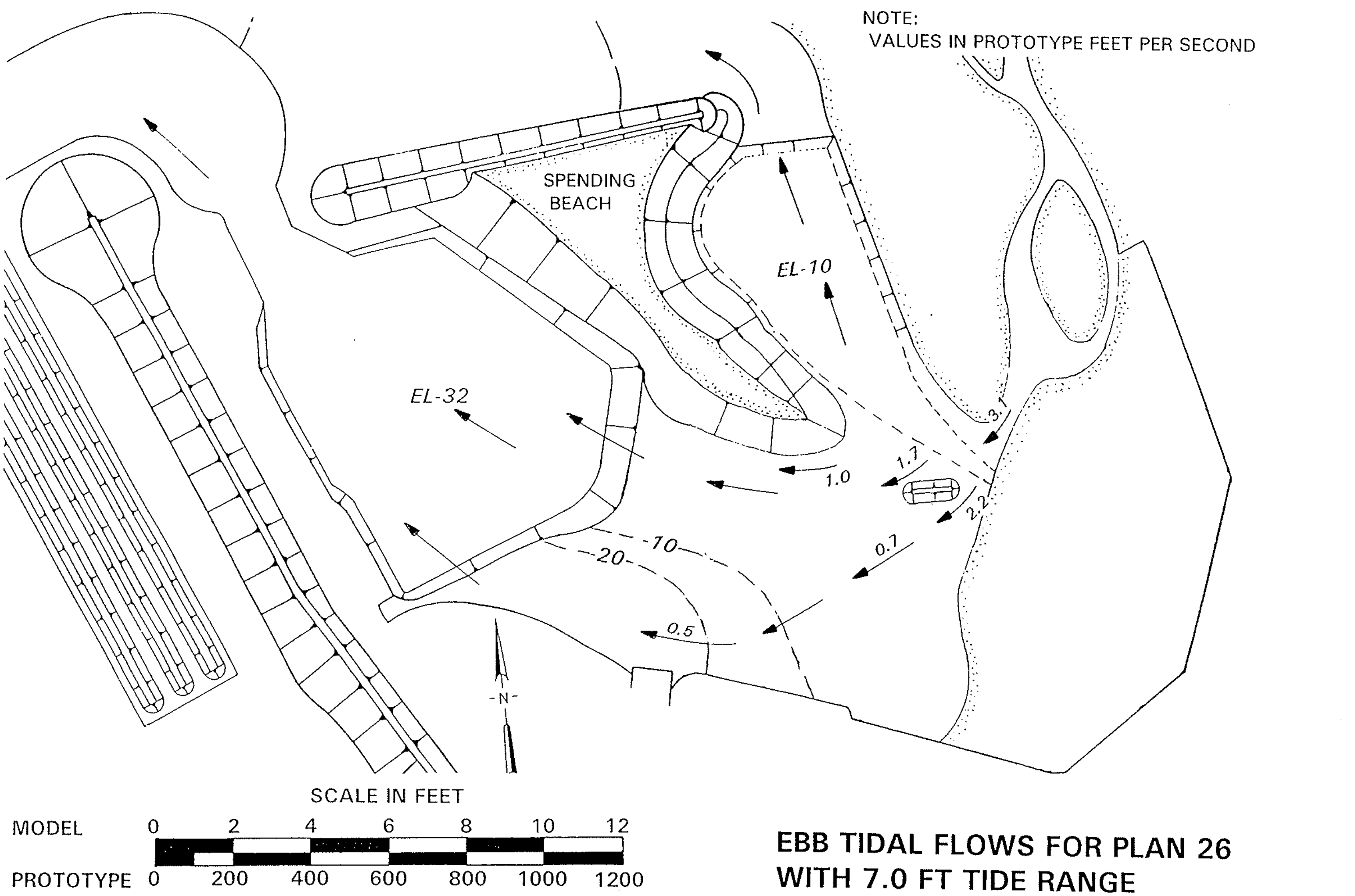
PROTOTYPE 0 200 400 600 800 1000 1200

CURRENT PATTERNS AND MAGNITUDES FOR PLAN 27 (20-SEC, 14-FT WAVES)





EBB TIDAL FLOWS FOR PLAN 26
WITH 3.2 FT TIDE RANGE



EBB TIDAL FLOWS FOR PLAN 26
WITH 7.0 FT TIDE RANGE

REPORT DOCUMENTATION PAGE

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13. ABSTRACT ***(Maximum 200 words)***

A 1:100-scale (undistorted) three-dimensional coastal hydraulic model was initially used to investigate the design of proposed harbor improvements at St. Paul Harbor, St. Paul Island, Alaska, with respect to wave and current conditions in the harbor and sediment patterns at the site. Wave-induced circulation and sediment patterns seaward of the main breakwater as a result of a submerged reef were investigated. Proposed improvements consisted of deepening the entrance channel, constructing a maneuvering area and installing a wave dissipating spending beach inside the existing harbor, and constructing a submerged reef seaward of the main breakwater. In this study, the model was reactivated to optimize flushing of Salt Lagoon and small-boat harbor improvements in St. Paul Harbor. The model reproduced approximately 2,865 m (9,400 ft) of the St. Paul Island shoreline, the existing harbor, the surface area of Salt Lagoon with its connecting channels to the harbor, and sufficient offshore area in the Bering Sea to permit generation of the required test waves. An 18.3-m-long (60-ft-long) unidirectional, spectral wave generator, an automated data acquisition and control system, and a crushed coal tracer material were used in model operation. It was concluded from study results that:

a. Preliminary experiments (Plans 13-18) revealed that all improvement plans would result in wave heights of less than 0.3 m (1.0 ft) in the small-boat mooring areas.

(Continued)

14. SUBJECT TERMS

Harbors	Tidal flushing
Hydraulic models	Wave dissipating spending beach
Sediment patterns	Wave-induced currents
St. Paul Harbor, St. Paul Island, Alaska	Wave protection

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13. ABSTRACT (Concluded).

b. Preliminary experiments indicated that with the originally proposed plans, sediment deposits would occur in the small-boat navigation channel. A breakwater extending southeasterly from the wave-dissipating spending beach, however, would prevent shoaling of the channel.

c. Preliminary experiments revealed that the location of the north breakwater was critical with respect to diverting tidal currents from the lagoon connecting channel toward the harbor basin and providing circulation.

d. Of the improvement plans investigated with the wave energy channel connected to Salt Lagoon north of the harbor, the 61-m-wide (200-ft-wide), +0.9-m (+3.0-ft) el channel of Plan 21 was the best energy channel configuration.

e. The improvement plan configurations of Plans 24 and 25 (26-vessel and 52-vessel basins, respectively) will provide adequate wave protection, shoaling protection, and harbor circulation for the new small-boat harbor.

f. Improvement in shoaling and circulation conditions for the existing harbor will be obtained with the installation of the sediment deposition basin, the southeasterly extension of the wave-dissipating spending beach, and the north breakwater (Plan 26).